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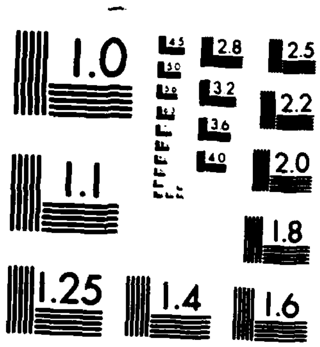

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Plans for the Long Term Upper Ocean Study evolved over several years. As the plans became more definite a two year period was devoted to engineering tests at the LOTUS site (34°N, 70°W). Many aspects of the proposed plans were implemented during this period in order to evaluate the performance of the equipment and instrumentation. This report presents a summary of the planning and testing periods up to but not including the first science deployments in May 1982. Historical data collected as part of the engineering tests are presented.

WHOI-82-53

LONG TERM UPPER OCEAN STUDY
(LOTUS)
A SUMMARY OF THE HISTORICAL DATA AND ENGINEERING TEST DATA

by

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and Nancy J. Pennington

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Woods Hole, Massachusetts 02543

December 1982

TECHNICAL REPORT

Prepared for the Office of Naval Research under Contract N00014-76-C-0197; NR 083-400.

Approved for Distribution: N.P. Fofonoff

N. P. Fofonoff, Chairman
Department of Physical Oceanography

Abstract

Plans for the Long Term Upper Ocean Study evolved over several years. As the plans became more definite a two year period was devoted to engineering tests at the LOTUS site (34°N, 70°W). Many aspects of the proposed plans were implemented during this period in order to evaluate the performance of the equipment and instrumentation. This report presents a summary of the planning and testing periods up to but not including the first science deployments in May 1982. Historical data collected at the LOTUS site prior to the engineering tests and the data collected as part of the engineering tests are presented.

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Acknowledgements

The engineering moorings were designed by members of the Ocean Structures and Moorings Section of Ocean Engineering Department who, in cooperation with the "WHOI Buoy Group", prepared, deployed and recovered the moorings.

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I. INTRODUCTION

The Long Term Upper Ocean Study (LOTUS) is an experiment designed to acquire and analyse a continuous two year set of measurements of the fluctuation of currents and temperature in the upper ocean, together with the local hydrography and meteorology. Data acquisition formally began in May 1982 with the deployment of a moored array of current meters, thermistor chains and meteorological sensors.

The plans for LOTUS evolved over a number of years. As the experiment began to take form, a two year period (1980, 1981) was devoted to engineering tests to ascertain whether the goals established during early planning stages could indeed be accomplished. This report will summarize the planning and testing that were associated with LOTUS up to the first science deployment in May 1982. It will begin by presenting a brief summary of the details and questions raised by previous experiments which led to the present design of the LOTUS experiment. The site chosen for the experiment will be presented followed by a description of the cruises made during the engineering test period. Data collected prior to and during the planning and testing periods will be presented in later sections according to the type of data (i.e. current meter, XBT, CTD).

a. Background of LOTUS

Numerous past experiments like Site D, MODE, POLYMODE, and the LDE have examined low-frequency motions in the deep ocean below 500 m, sometimes extending to within 200 m of the surface, and sometimes lasting a year or more. An even larger number of upper-ocean studies like the old Site D work, MILE, and JASIN exist, usually concentrated in the top hundred meters or so and often related to air-sea interaction. All of the upper-ocean studies are short: a few weeks is typical (i.e., the length of one oceanographic cruise).

This disparity in experiment length is a consequence of two items, one scientific and one technical: the scientific reason is that the energetic, unexplored deep motions are synoptic-scale while many obvious yet not *understood* upper-ocean motions occur in a few hours to a few days, for example mixed-layer deepening and Ekman dynamics. Longer time-scale upper-ocean problems such as the horizontal patchiness of thermocline formation in the Spring, or convective overturn in the Winter, are no less important but are more difficult experiments simply because they do blend the detail of upper-ocean space and time scales with the duration typical of deep-ocean experiments.

This, then, is the technical reason for short upper-ocean experiments: the required detail, accuracy, and even content of the measurements have often demanded fragile or power-hungry instrumentation and observations from ships. Upper-ocean velocity profiles and temperature-salinity relations are highly variable, yet there is often a need for density and shear measurements to describe instability processes at the base of the mixed layer and top of the thermocline. Since buoy-mounted sensors have been unable to provide these data, ship-based experiments using CTD's, velocity profilers, and towed instruments have become the norm for upper-ocean studies, and hence the experiments have been about one cruise (sometimes two!) long.

Clearly, as buoy-mounted, free-drifting, air-dropped, and even satellite sensors become able to measure the kinds of parameters needed with the accuracy, reliability, and duration required, long-term and large-area upper-ocean experiments will be planned and performed. JASIN (Pollard, 1978) was a tentative step in this direction. Meanwhile, there are a few kinds of long-term scientific questions in the upper-ocean that can be technically addressed with existing methods, for example the modulation of the internal wave field by low-frequency and seasonal processes, and the character of the low-frequency currents themselves.

The LOTUS experiment is designed to exploit present technology in the pursuit of three immediate scientific objectives:

- what is the low-frequency energy content in the upper ocean?
- what is the low-frequency modulation (envelope) of the internal wave field?
- what is the upper-ocean response to wind forcing, during different meteorological and oceanographic regimes?

The first question is mainly descriptive, but the second and third allow us to go further and ask to what extent the fluctuations and response are due to observable quantities such as atmospheric forcing, oceanic eddies or rings acting as sources, horizontal variability such as fronts.

One motivation for LOTUS was the hypothesis of a universal level of internal wave energy of around 4×10^3 J m^{-2} (Garrett and Munk, 1979). In fact, the level is not exactly constant at any one location (factors of 3 variability within a few days are common, see Briscoe (1983)), and also apparently varies between locations (the Mediterranean and the Western North Atlantic seem to differ by as much as a factor of 10). As Wunsch (1975) and McComas and Müller (1981) suggest, strong clues to the dynamical balances and the sources and sinks are likely to be found in just those situations where the hypothesis of a universal level is most strongly violated. This might suggest making internal wave energy measurements all around the world, and producing energy contour plots on a Mercator projection of the globe, but first it seems advisable to sit at one location for an extended period of time and see what kind of fast (a few days) and slow (a few months) variability could occur in the internal wave field at one site. One might discover that the mean energy over one week is an excellent descriptor of the site, or that one year is necessary to give a stable result. The possibility and style of a geographical survey can then be determined.

These were the considerations which led to the formalized plans of a long term upper ocean study. The remainder of the report will be concerned with the study site and the engineering test period.

b. LOTUS Site Selection

During the planning stages the experiment site shifted from several potential locations in the North Atlantic to its final location at 34°N, 70°W. The site chosen is a 2 degree square area centered around the old WHOI "Site L" at 34°N, 70°W, which was selected for its logistic convenience and because a variety of oceanographic conditions could be expected there, namely eddies, once-in-a-while Gulf Stream rings, strong atmospheric forcing in the Fall, deep convective mixing just to the North, and a strong thermocline in the late Summer. Figure 1 shows the location with respect to the mean axis of the Gulf Stream.

The oceanography of the site is fairly homogeneous in terms of mean monthly properties. Figure 2 shows that one-degree averaged, monthly

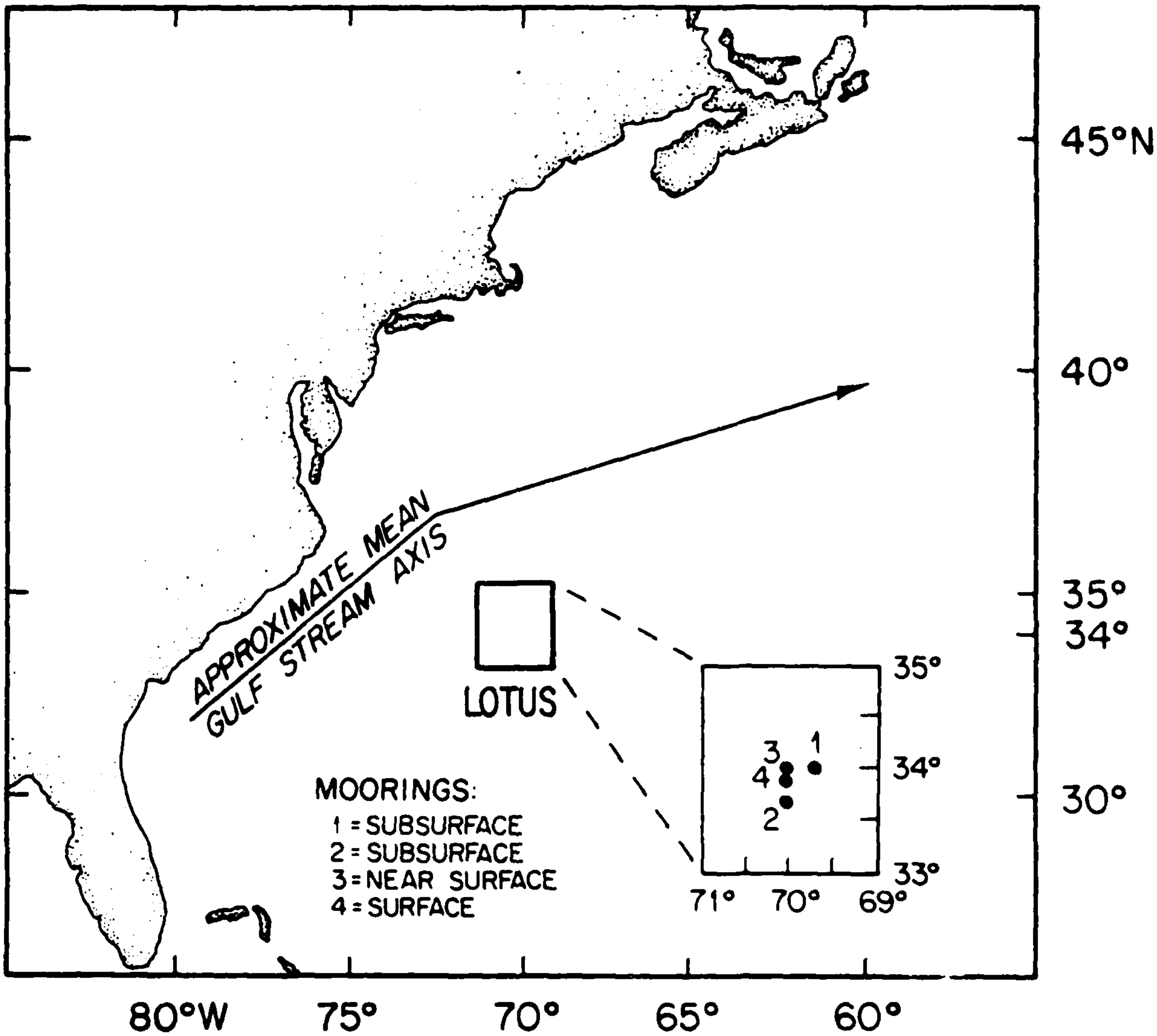

Figure 1: Location of the LOng-Term Upper-ocean Study (LOTUS) area.

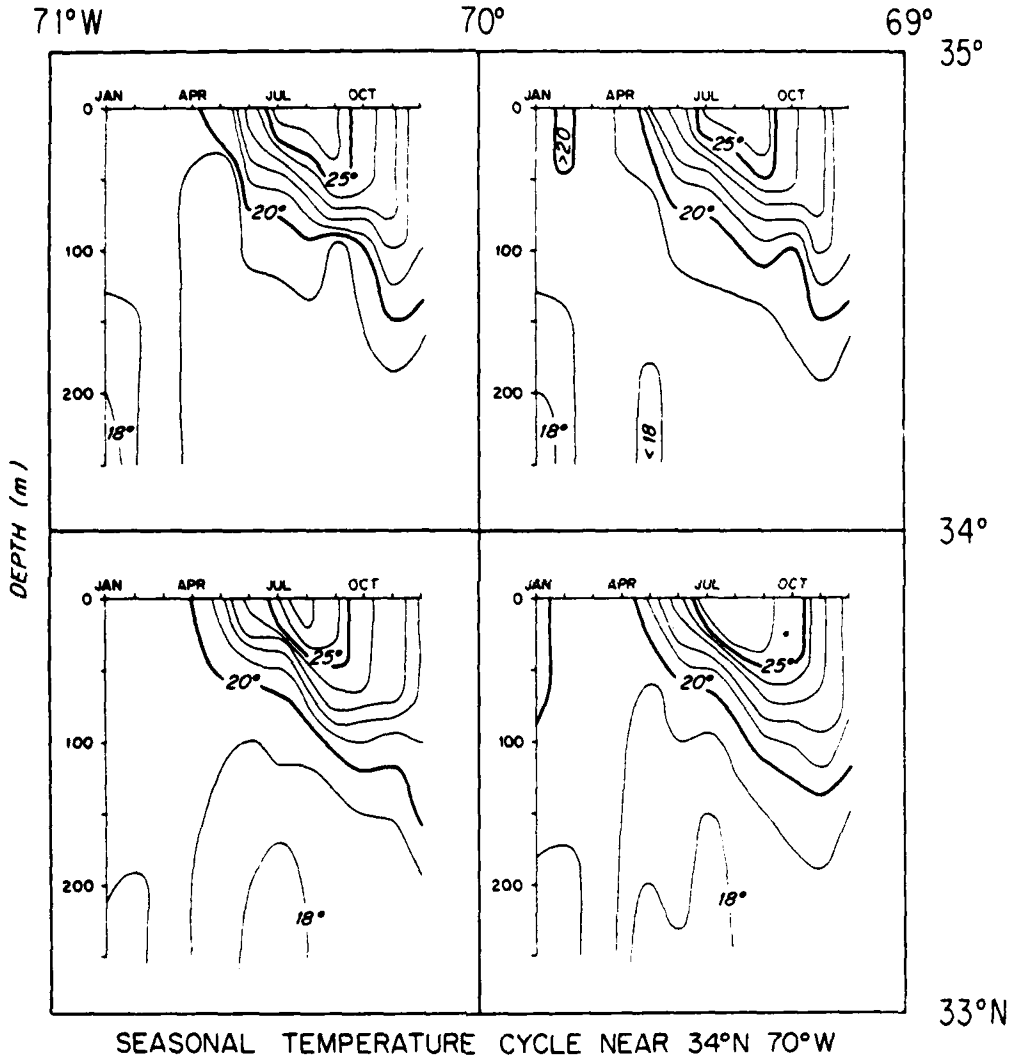

Figure 2: Contoured monthly-average temperature profiles from WHOI BT atlases.

temperature profiles are similar for the four one-degree squares surrounding Site L. Seasonal thermocline formation begins in April and is complete by August. Mixed-layer deepening begins in September and terminates with deep-convective mixing in February. Figure 3 illustrates that the one-degree square monthly average sea-surface temperatures surrounding Site L are similar from year to year. (Note how cold the winter of 1977 was, a period of strong formation of "18° water".)

The bathymetry of the area is flat and featureless as the site is situated on the Hatteras abyssal plain. A bathymetric survey conducted during OCEANUS cruise 96 is shown in figure 4. The contours indicate a gentle slope to the southwest of approximately 1 meter per 10 kilometers.

Navigation throughout the engineering period and all positions shown in this report are based on Loran-C and the geographical calculation performed by the Northstar 6000 Loran-C unit.

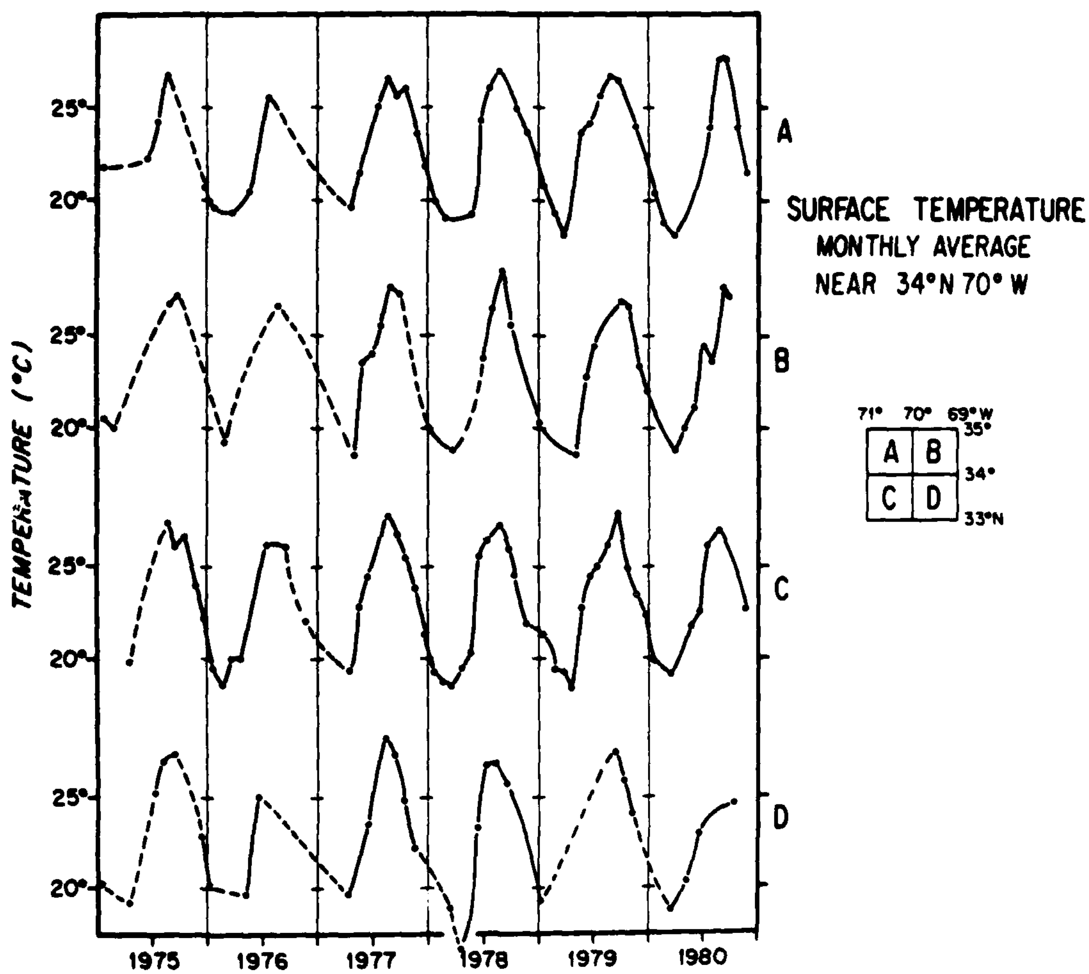

Figure 3: Sea-surface monthly average temperatures from "Gulf Stream" monthly summaries.

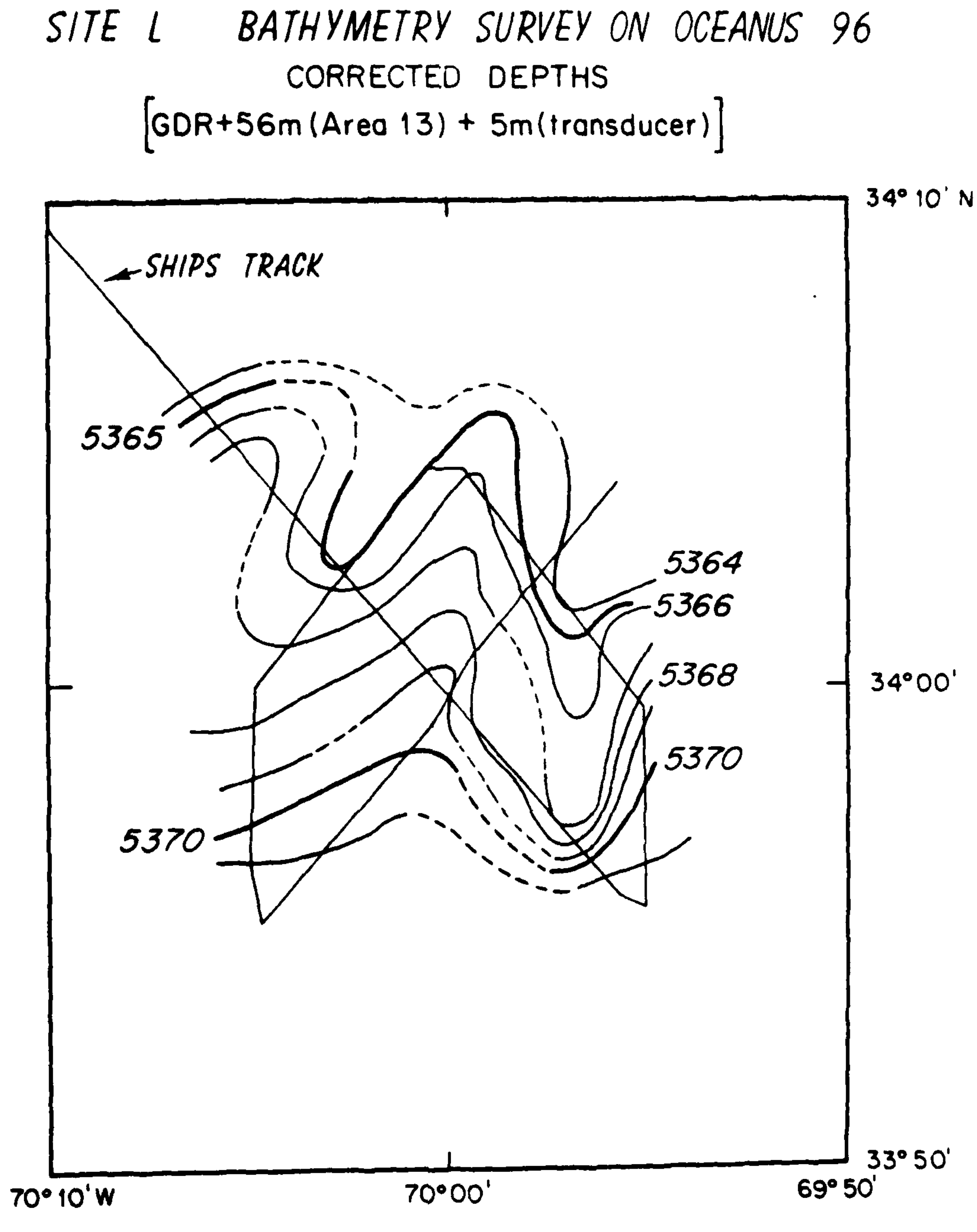

Figure 4: Measured bathymetry near Site L.

II. ENGINEERING TEST PERIOD

In preparation for the LOTUS experiment a two year period was devoted to the acquisition and testing of equipment and instrumentation. Of primary concern during this period was the mooring array to be used in the experiment. The proposed array consisted of a surface mooring, a near-surface mooring and two subsurface moorings. The surface mooring was to be used to make the very near-surface (5-100 m) current and temperature measurements as well as meteorological measurements from the buoy. The surface mooring current and temperature measurements were to be largely made by Vector Measuring Current Meters. The near-surface mooring was to be heavily instrumented in the 100 m to 500 m depth range with deeper measurements as well and the subsurface moorings were to be instrumented at several depths below 500 meters. These non-surface moorings were to be instrumented with Vector Averaging Current Meters. Confident from past experience that the subsurface moorings could survive and perform well, only the surface and near-surface *moorings were* tested during the engineering period. The engineering moorings carried at least one current meter and thermistor chain along with some instrumentation such as tensiometers and depth recorders for monitoring the behavior of the mooring.

In addition to the mooring work the implementation of a newly acquired internally recording CTD and shipboard processing system was also of primary concern during the engineering period. It was during this time that an in situ calibration system compatible with the CTD was designed, tested and made operational.

During the six engineering test cruises to the LOTUS site, CTD and XBT data were collected whenever possible in order to begin to compile seasonal hydrographic data from the area.

The engineering test cruises to site L are outlined in the following section, which describes the moorings that were deployed and recovered, the extent of the CTD and XBT work, and any cooperative work with other investigators. Table 1 summarizes the engineering test cruises to the LOTUS site.

Aside from the engineering data and its information about the mooring behaviour, some scientific data were obtained during the engineering mooring deployments. These data include two current meter records, and two time series of temperature data from the thermistor chains. These data are presented below along with CTD and XBT data obtained during the engineering cruises. Each type of data is presented in individual sections. The current meter data section is the only section which contains pre-engineering test data. The last data section contains some telemetered data from the second LOTUS surface buoy (LOTUS-2) including information on the track of the buoy about its watch circle.

a. Chronology

May 1980: OCEANUS cruise number 79 was the first of a series of engineering test cruises for the LOTUS experiment. During this cruise a surface mooring (Number 694) and a near-surface mooring (Number 693) were deployed near 34°N, 70°W. Mooring 693 was deployed at 34°02.8'N, 70°00.3'W and 694 was deployed at 33°59.8'N, 70°00.1'W. Mooring diagrams appear in figures A-1 and A-2. The surface mooring, designated LOTUS-1, had a buoy with an Aanderaa meteorological package and a Vector Measuring Wind Recorder sensor. The buoy was a 12 foot discus buoy previously used in IWEX (Internal Wave Experiment) in 1973 and also in earlier deployments. The surface mooring contained a prototype SEA-LINK Vector Measuring Current Meter (mechanical assembly only) and two Aanderaa thermistor chains. The near-surface mooring utilized the IWEX float; the float was at 60 m depth with a Vector Averaging Current Meter at 100 meters. Also during this cruise two expendable bathythermograph (XBT) sections were made along 70°W between 33°N and 39.7°N during the trip to and from the LOTUS area. In cooperation with D. Hurd (WHOI) a series of dissolution samples were placed on the near-surface mooring in order to evaluate the deep ocean effects.

August 1980: OCEANUS cruise number 85 was the second engineering test cruise of LOTUS. The objectives of this cruise were to test a newly acquired CTD unit and to recover the surface mooring set in May 1980. Upon arrival at 34°N, 70°W the surface buoy was not found, though both the acoustic release and acoustic tracking module were present indicating that the bulk of the mooring remained on site. Only the glass balls and acoustic release were recovered by dragging with improvised gear. Testing the CTD unit proceeded with little difficulty and a total of 5 CTD stations were made in the LOTUS area. In addition an XBT section was made along 70°W between 34°N and 39.5°N.

November 1980: KNORR cruise 85 to 34°N, 70°W was the third engineering test cruise for LOTUS, and was cooperative with the Gulf Stream Extension project of N. Fofonoff. During this cruise the near-surface mooring (Number 693) set in May 1980 was recovered. Additional testing of the CTD system and a Fall CTD station from the LOTUS area were made. Further dragging for the LOTUS-1 surface mooring (Number 694) was attempted but was unsuccessful. As with the previous cruises an XBT section between 34°N and 39.4°N along 70°W was also completed. Additional CTD's and XBT surveys were obtained during this cruise in conjunction with the Gulf Stream Extension project.

February 1981: KNORR cruise 87 to the LOTUS area was the fourth cruise of the engineering test period. The sole purpose of this cruise was to obtain CTD data from the LOTUS site during the winter season. Ten CTD stations were made in the LOTUS area as well as several XBT sections including two sections along 70°W between 33°N and 40°N.

May 1981: OCEANUS cruise number 96 was the fifth engineering test cruise to the LOTUS area. During this cruise a second surface mooring, LOTUS-2 (mooring number 733), was deployed at 33°59.9'N, 69°59.7'W. The surface mooring buoy was a newly designed 10' diameter discus buoy. The mooring design is shown in figure A-3. It had a Vector Measuring Wind Recorder sensor, a J-tec anemometer and an ARGOS satellite transmitter which could transmit tension in the mooring line, sea and air temperature, battery and regulated voltage, water level in the buoy and the relative wind direction. From the

ARGOS and NOAA-NESS links we could monitor all the variables as well as the buoy position. For more information on the telemetered data see section IIf. The surface mooring contained a Vector Measuring Current Meter at 37 m and two paralleled 100 m Aanderaa thermistor chains between 50 and 150 meters. In addition a C. S. Draper Labs Profiling Current Meter test mooring was deployed at 34°01.8'N, 70°02.7'W in cooperation with C. Eriksen of MIT. A series of seven spring CTD stations were occupied in the LOTUS area and an XBT section was completed between 33°N and 40°N along 70°W. Additional CTD's and XBT sections were made outside the LOTUS area in cooperation with T. Joyce (WHOI) during his tests of a doppler acoustic profiler.

September 1981: OCEANUS cruise number 103 was the sixth and last engineering test cruise for LOTUS. During this cruise the second surface mooring, LOTUS-2, set in May 1981 was recovered, along with the test PCM mooring. Three CTD stations were made in the LOTUS area as well as an XBT section between 34.2°N and 37.8°N along 70°W. Additional CTD's and XBT surveys were conducted outside the LOTUS area in conjunction with cooperative work with C. Paulson of Oregon State University who was collecting towed thermistor chain data. Another attempt was made at dragging for the first failed surface mooring using modified dragging gear. The mooring was successfully recovered. Unfortunately the mooring had parted at 5 m depth below the prototype SEA Link Vector Measuring Current Meter due to a faulty master link. Everything below that point was recovered. The Aanderaa thermistor chains had been affected to varying degrees by the bottom pressure but there were recoverable data. A summary of the engineering test cruises for LOTUS appears in Table 1.

TABLE 1: A Summary of the Engineering Test Cruises for LOTUS Showing Principal Work and Cooperative Efforts

Dates	Cruise	LOTUS Work	Other Work
1-9 May 80	OCEANUS 79	Set test surface mooring LOTUS-1, and test near-surface moorings.	Hurd (G&G) dissolution samples on near-surface mooring.
2-11 Aug 80	OCEANUS 85	Attempt LOTUS-1 recovery. Test CTD/IR.	
16 Nov-6 Dec 80	KNORR 85	Recover test near-surface mooring. Drag for LOTUS-1. Use CTD/IR.	Hurd Samples. Fofonoff CTD and mooring work.
25 Feb-4 Mar 81	KNORR 87	CTD/IR stations.	
11-21 May 81	OCEANUS 96	Set test surface mooring LOTUS-2, and make CTD/IR profiles. Test shipboard processing system.	Joyce warm core ring studies with test of doppler acoustic profiler. Set test Eriksen PCM.
10-18 Sept 81	OCEANUS 103	Recover LOTUS-2. Successful drag for LOTUS-1. CTD/IR profiles.	Paulson towed thermistor chain. Recover test Eriksen PCM.

b. Current Meter Data

Historical current meter records obtained prior to the LOTUS engineering test period are shown in figures 5-7. The current meter data presented in these figures were obtained by Geodyne Model 850 current meters. These instruments burst-sample compass, vane, and rotor values and store them plus time information on 1/4 inch two track magnetic tape cartridges. Random erroneous values and systematic errors were edited from the burst sample data, then a vector average was formed for each data burst.

The data in figure 6 and the three deep records in figure 7 are suspect since they represent rotor-vane measurements deep on a surface mooring: the time scales and relative behavior may be usable, but the amplitudes may be overestimated by a factor of 2 or more. Even the 14 m measurements (figures 5 and 7) are probably modest overestimates. Nevertheless, surface currents of 110 cm/sec (figure 7) are estimated and strong currents to 500 m (figure 6) seem possible.

During the engineering test period of LOTUS two current meter records were obtained. A Vector Averaging Current Meter (VACM) record from the near-surface mooring (Number 693) (figure A-1) deployed for 7 months starting in May 1980, and a Vector Measuring Current Meter (VMCM) record from the LOTUS-2 surface mooring (Number 733) (figure A-3) deployed in May 1981.

The VACM and VMCM differ mainly in their flow-sensing elements: the VACM uses a Savonius rotor and a vane to give speed and direction which are resolved against an internal compass to east and north components for vector averaging and recording on tape, whereas the VMCM uses orthogonal cosine-response propellors that sense directly the flow components which are then rotated relative to an internal compass to permit vector averaging and data recording. In addition the VACM had a temperature sensor (thermistor) embedded in its endcap.

Both types of current meters record on Phillips-type cassettes which are transcribed to 9 track computer compatible tapes, converted to scientific units, edited to remove launch and retrieval transients and linearly interpolated across missing and erroneous data cycles if necessary.

The near-surface test mooring gave a VACM record at a nominal 114 m depth (figure 8) from May to December 1980 that shows nearly 50 cm/s speeds, fluctuations of a factor of 3 in the energy in various high frequency bands (figure 9), factor of 10-20 fluctuations in the tidal-inertial band and a spectrum (figure 10) showing strong inertial motions and primarily clockwise M_2 tidal ellipses.

The LOTUS-2 surface mooring test from May to September 1981 provided a VMCM test record from 36 m depth. The first two weeks of the test record were perfect and are shown in figure 11. Strong inertial motions (see also peak in figure 12) occur in the middle of the record. The beginnings of the passage of a Gulf Stream ring occur at the end of the record where speeds exceed 60 cm/s.

During the same cruise on which the LOTUS-2 surface mooring was deployed, a Draper Labs-MIT profiling current meter (PCM) mooring was deployed less than 6.5 km to the northwest. The PCM profiles along the upper portion of a subsurface mooring by adjusting its buoyancy under computer control (Eriksen et al., 1982). Measurements of current, temperature, and conductivity are made while the instrument travels typically between 20 and 250 meters depth. The current measurements are made by a 10 cm diameter, two-axis Marsh-McBirney model 515 spherical electromagnetic current sensor. Temperature is sensed by a Fenwall thermistor probe and conductivity is measured by a Plessy induction type conductivity cell.

The PCM excursion bracketed the VMCM depth (36 meter) on the LOTUS-2 surface mooring. Figure 13 is a comparison of the VMCM record and the current measurements by the PCM.

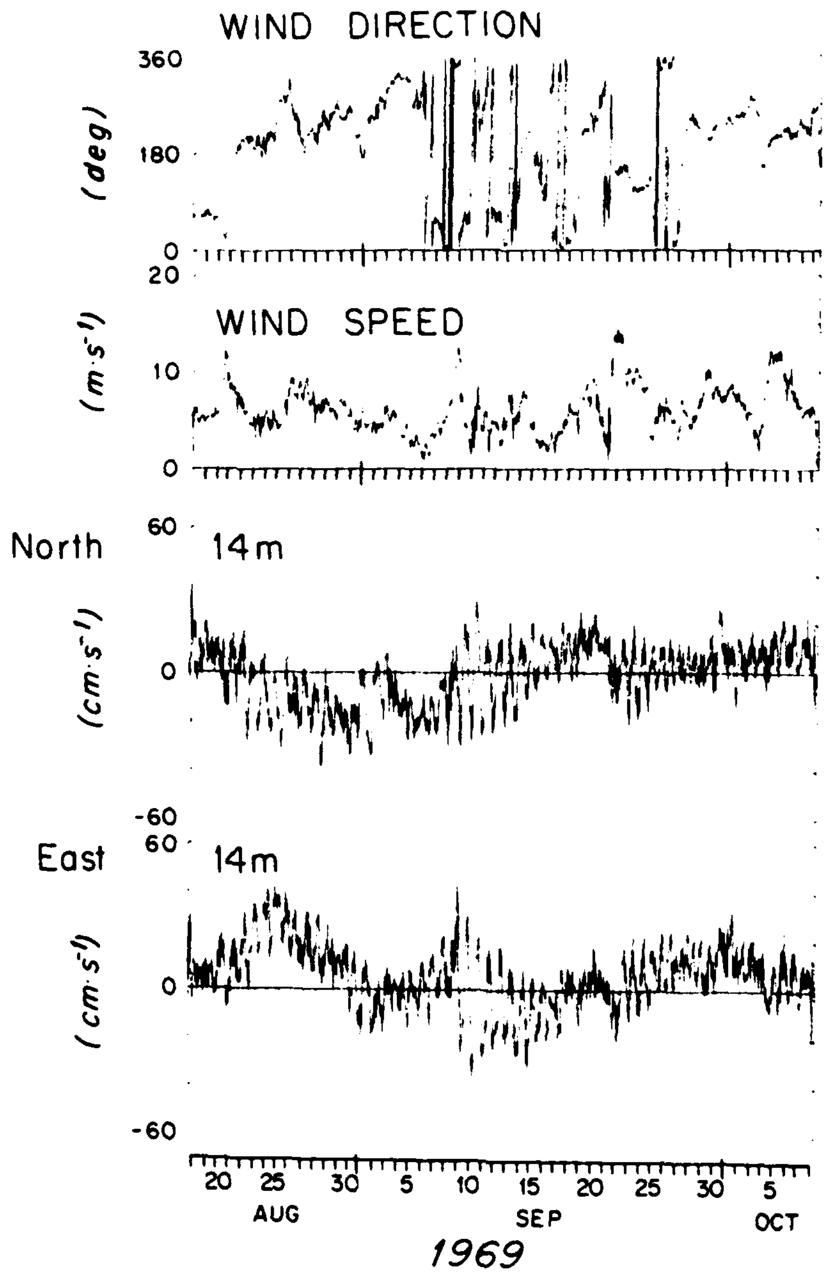

Figure 5: Wind and surface currents (850 CM) from WHOI surface mooring 314 in summer 1969 at Site L.

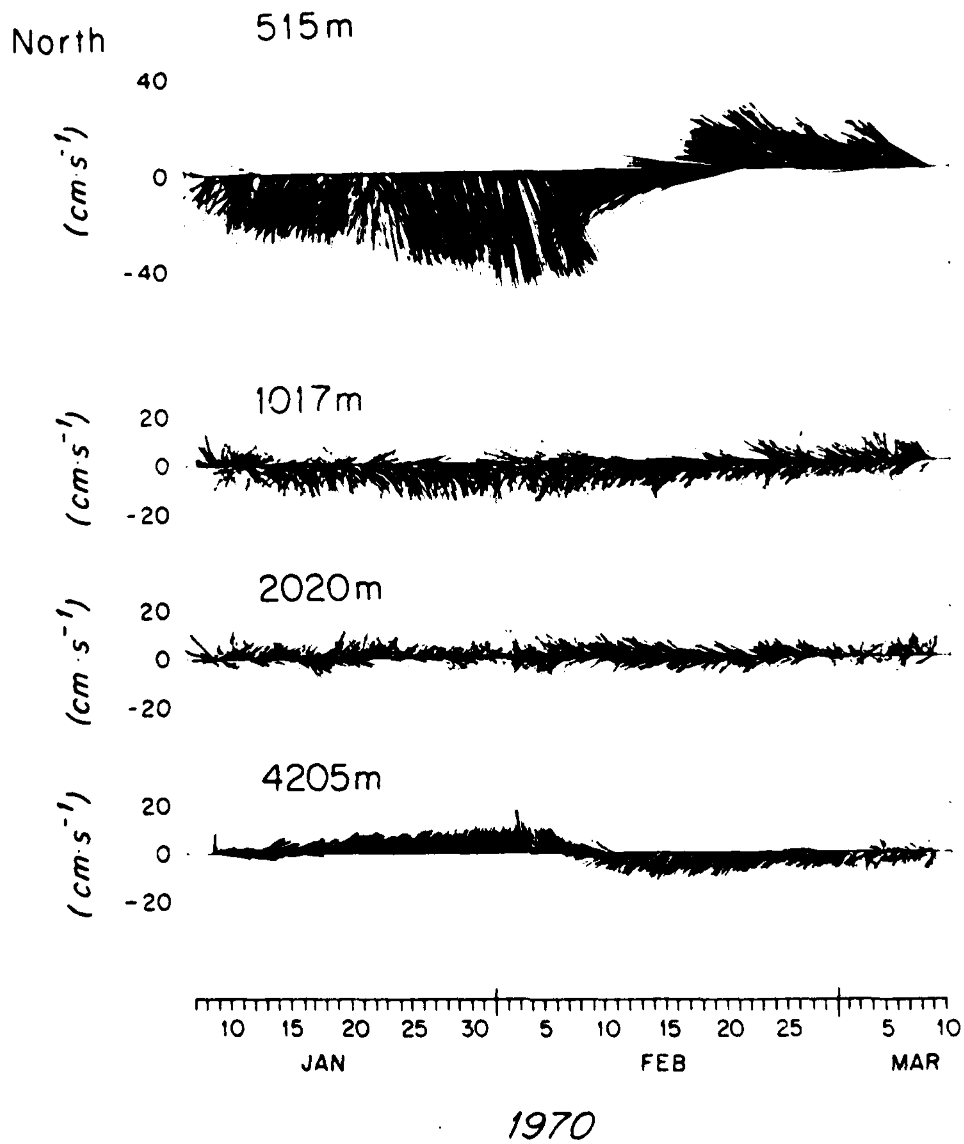

Figure 6: Deep currents (850 CM) from WHOI surface mooring 323 in winter 1970 at Site L.

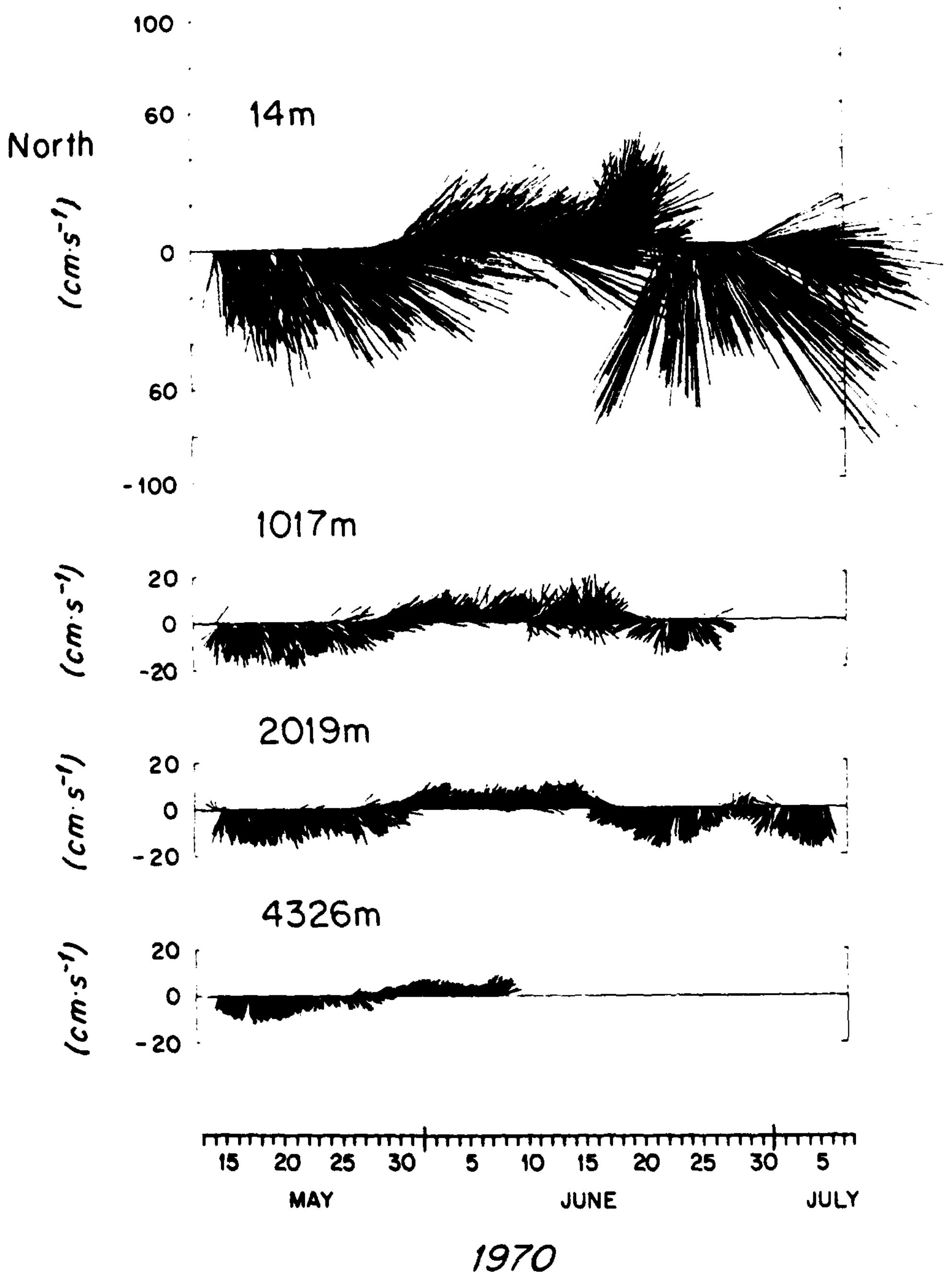

Figure 7: Surface and deep currents (850 CM) from WHOI surface mooring 334 in spring 1970 at Site L.

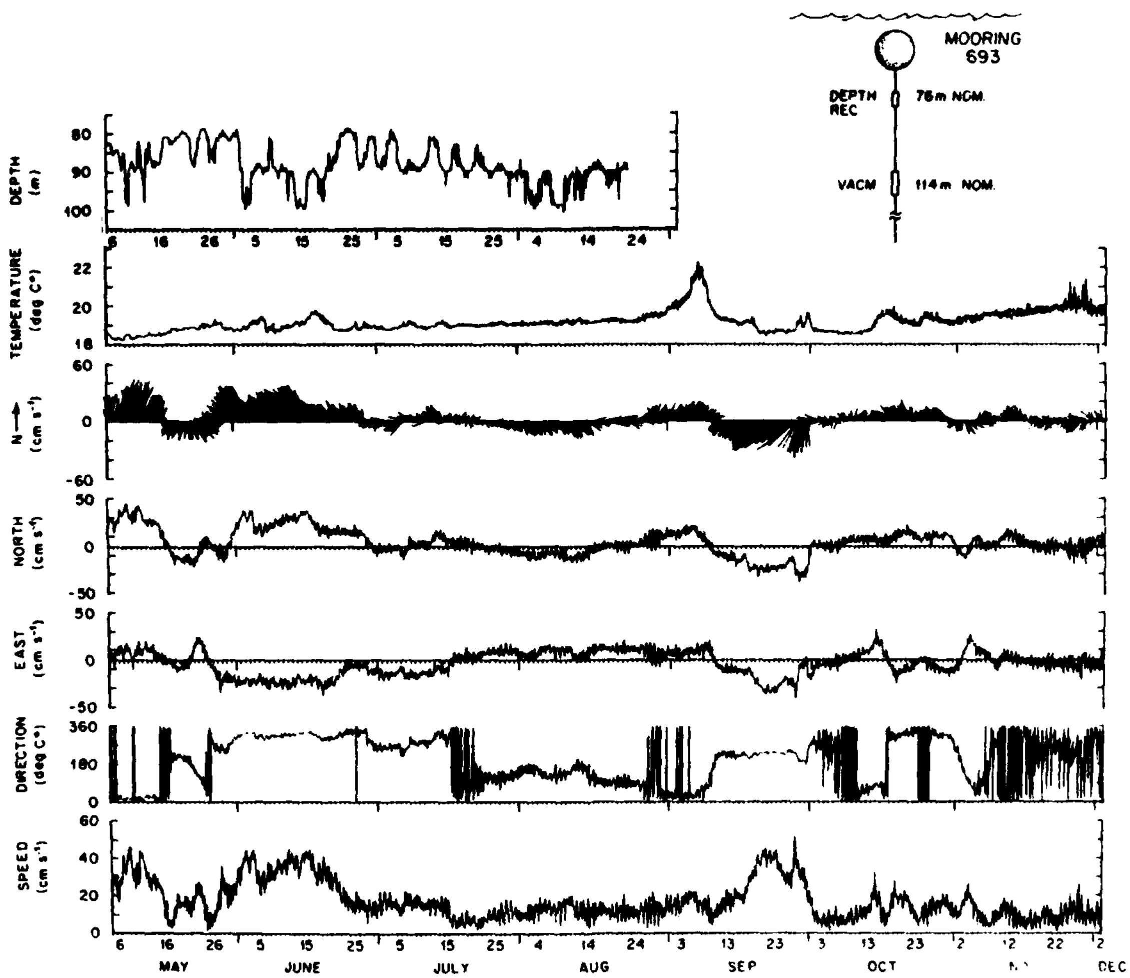

Figure 8: Data from the engineering deployment of a near-surface mooring at Site L from May 5 to December 2, 1980. A depth recorder at 76 m and a VACM at 114 m (nominal depths) were included to evaluate the performance of the mooring. The depth recorder failed on September 2. The current meter returned a full length record of current and temperature.

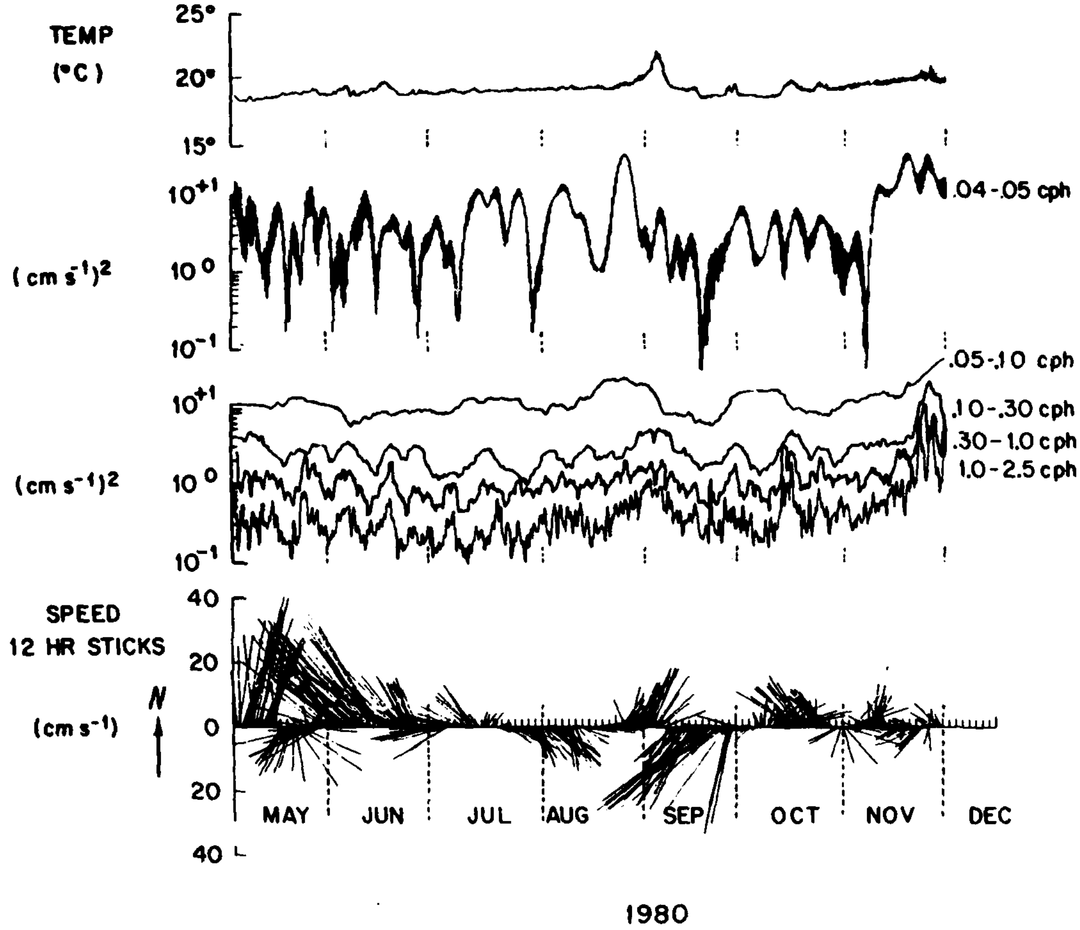

Figure 9: The time series of currents at 114 m at Site L was band pass filtered to examine the variability in various internal wave and inertial frequency bands. For each pass band, the quantity $u^2 + v^2$ is plotted. The four internal wave bands (.05 - .10, .10 - .30, .30 - 1.0, and 1.0 - 2.5 cph) were smoothed by running averages of different duration so that the bandwidth - time products for the four bands were the same and the fluctuation statistics would be similar. Temperature and 12-hour averaged current stick vectors are also shown.

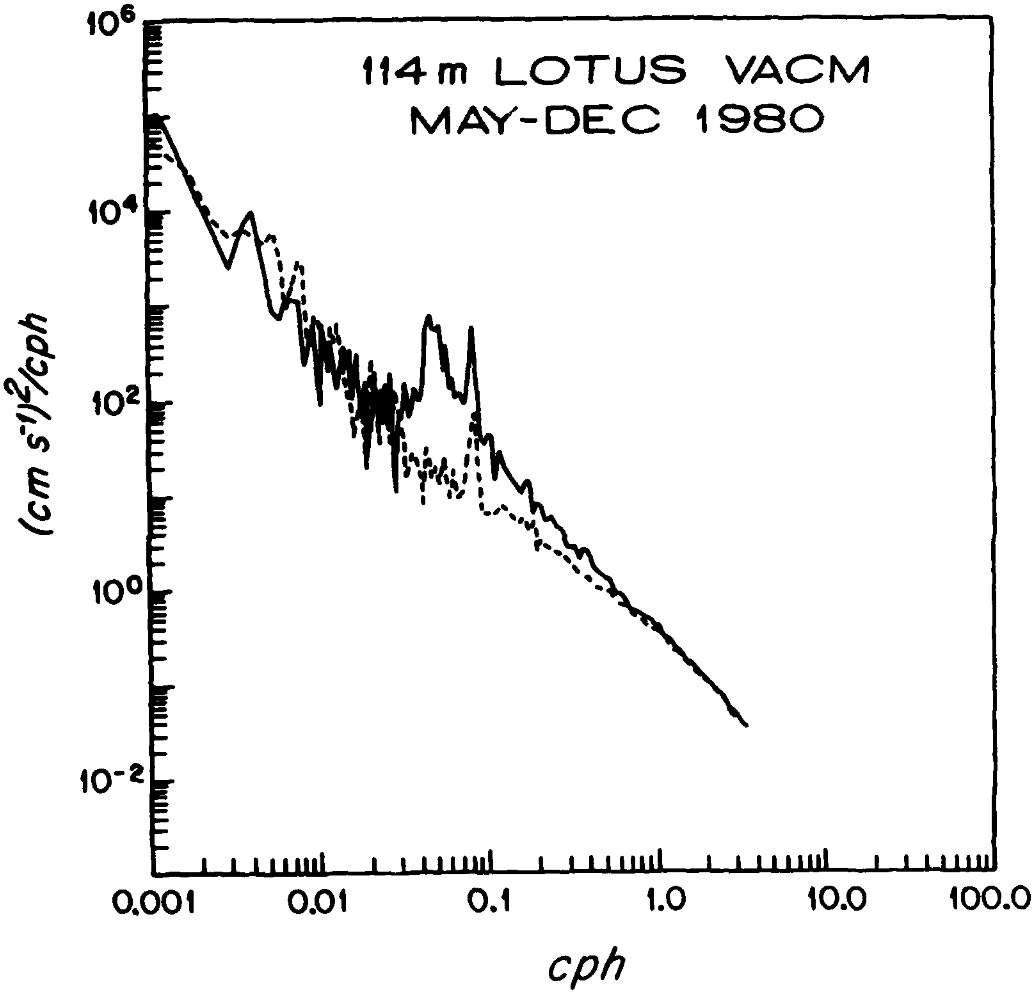

Figure 10: Rotary autospectrum of currents shown in Figure 9. Solid line is clockwise, dashed counter-clockwise.

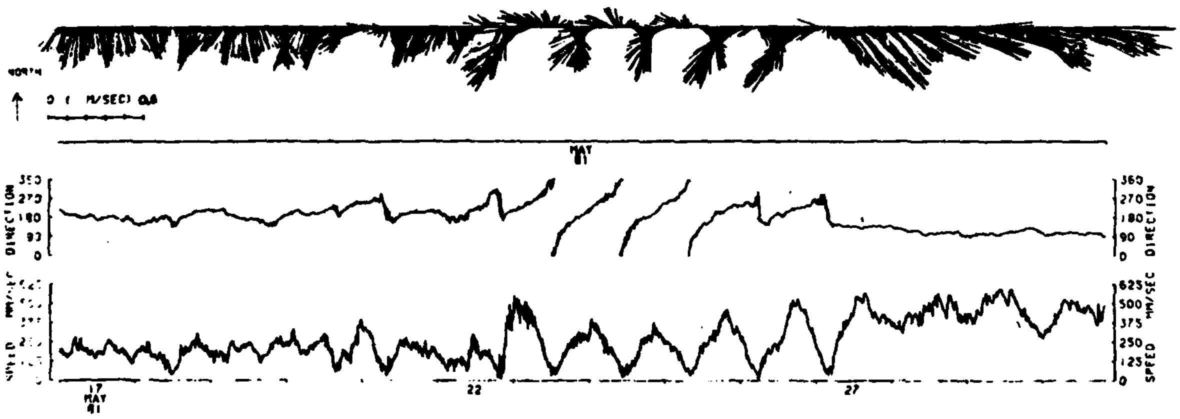

Figure 11: Currents at 36 m depth from a test VMCM on LOTUS-2 surface mooring; record covers 17-30 May 1981.

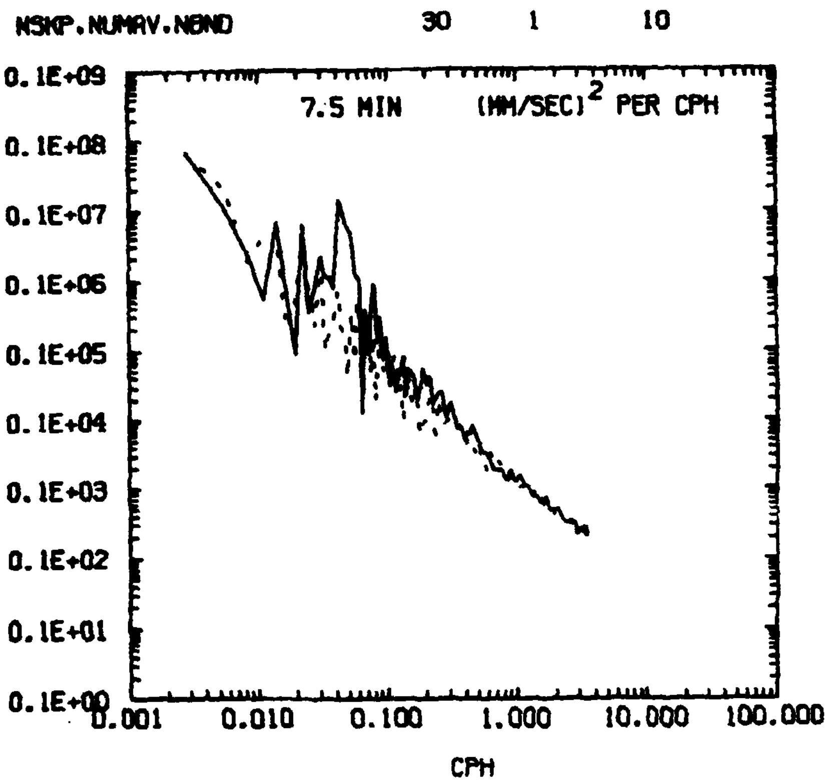

Figure 12: Rotary autospectrum of currents shown in Figure 11. Solid line is clockwise, dashed is counter-clockwise.

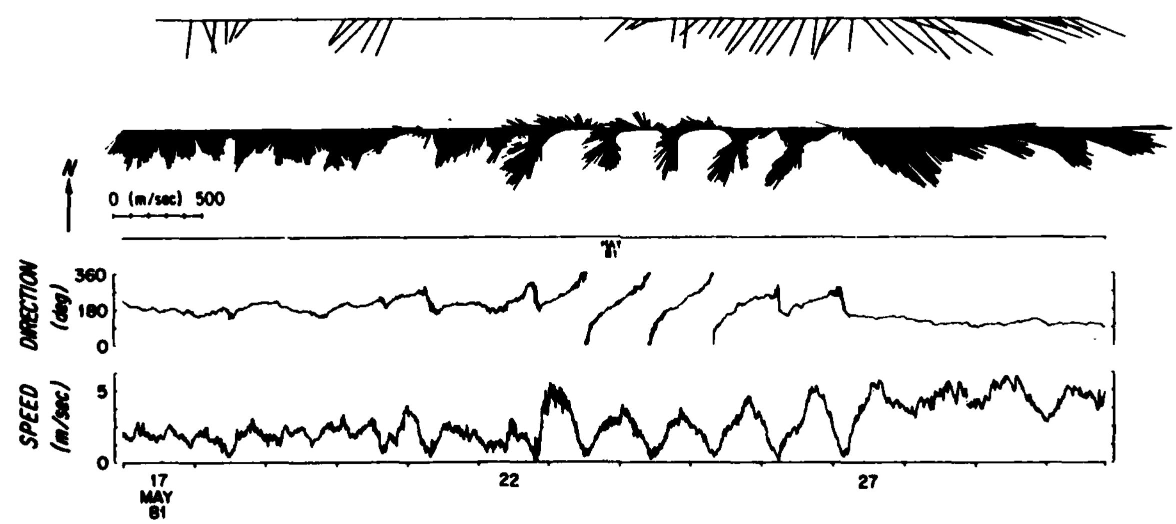

Figure 13: Comparison of currents measured at 36 m depth from a test VMCM on the LOTUS-2 surface mooring and the currents measured by Draper Lab's profiling current meter (PCM). LOTUS-2 and the PCM test mooring were set during OCEANUS 96 in May 1981.

c. Thermistor Chain Data

On each of the LOTUS moorings deployed during the engineering test cruises there was at least one Aanderaa thermistor cable and recording unit. For various reasons which will be discussed below there was less than 100% data return from these instruments. The instruments deployed, problems encountered and the data return will be presented in this section.

The Aanderaa thermistor chain consists of a recording unit and thermistor cable. The thermistor cables used during the LOTUS engineering period were of two types. The older type used were 30 meter long oil filled PVC hose with 11 thermistors built-in along its length (thermistor spacing = 3 meters). Cables of newer design also used during this period were 100 meter long polyurethane cables with 11 thermistors molded to the outside of the cable (thermistor spacing = 10 meters).

The recording unit is mated with the thermistor cable by a watertight connector. All the thermistor cables deployed during the engineering tests of LOTUS were connected to Aanderaa model TR-1 recorders which record the temperature data on 1/4 inch reel to reel magnetic tape. The temperature range the instruments were capable of measuring was 10.08 to 36.04°C. The resolution of the temperature measurements is .1% of the temperature range or .025°C.

The recording units were held in stainless steel brackets with strength members that fastened in line with the mooring. The thermistor cables were attached to the mooring wire by clamps manufactured by the Stauff Corporation. These clamps independently grasp the mooring wire and thermistor cable and hold the two in a parallel configuration.

The near-surface mooring (Number 693) (figure A-1) deployed in May 1980 had a single 30 m thermistor chain between 125 and 155 meters depth. Upon recovery it was determined that this instrument had experienced a tape transport problem which appeared to have occurred during deployment. Tape from the full supply spool slipped off the spool and fell behind it. As the tape continued to advance it tightened up on the supply spool shaft and prevented any further tape advancement.

The surface mooring (Number 694) (figure A-2) also deployed in May 1980 had two 30 m thermistor chains between 13.5 and 43.5 and between 53.5 and 83.5 m. Loss of the surface buoy caused the entire mooring to fall to the bottom (5360 m depth). Unfortunately the recording unit pressure cases were only rated to 2000 m. Recovery of the mooring during dragging operations from OCEANUS cruise number 103 revealed that the upper instrument had been crushed by the water pressure which prevented any recovery of the data tape. The lower instrument however was deformed but had continued to operate throughout the duration. The data obtained from this instrument is shown in figure 14. The data are truncated part way through the deployment because the temperature measurements went off scale when the mooring fell to the bottom.

The surface mooring (Number 733) (figure A-3) deployed in May 1981 had two paralleled 100 m thermistor chains between 45 and 150 meter depth. This was done so that in the event of failure of either thermistor chain there would be a back up unit in the same depth range. The two thermistor chains were offset by 5 m to give a 5 m sensor spacing. This configuration proved useful because one of the two instruments experienced an encoder bearing failure, which prevented any data from being recorded by that instrument. The other instrument recorded good data from approximately 75% of the deployment. The data from this instrument appear in figure 15.

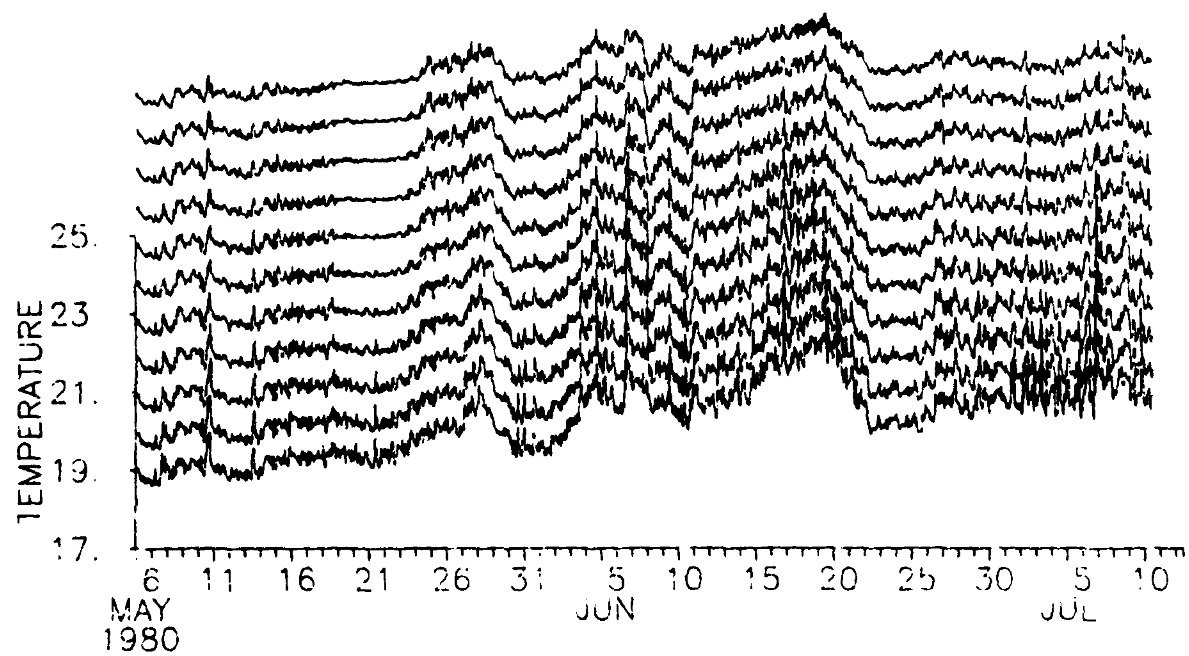

Figure 14: Time series of temperature data from the 30 m long Aanderaa thermistor chain located between 53.5 and 83.5 meters depth on the LOTUS-1 surface mooring. Thermistor spacing is 3 meters. Each temperature series has been offset by 1°C from the previous deeper series for ease of presentation.

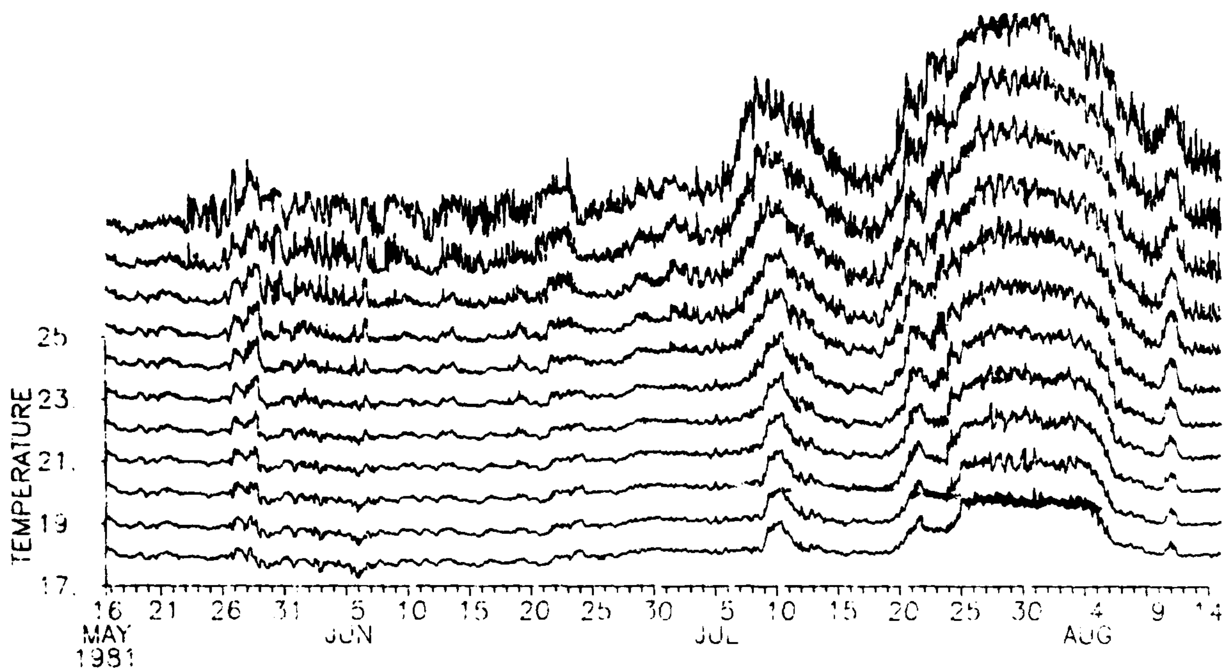

Figure 15: Time series of temperature data from the 100 m long Aanderaa thermistor chain located between 50 and 150 meters depth on the LOTUS-2 surface mooring. Thermistor spacing is 10 meters. Each temperature series has been offset by 1°C from the previous deeper series for ease of presentation.

d. Expendable Bathythermograph Data

During each LOTUS cruise one and sometimes two XBT sections were made along 70°W between Site L and nominally 40°N. This section of the report presents for each cruise a chart showing individual XBT locations and the corresponding XBT section. Since the cruises were planned for each season beginning in the spring of 1980 (OCEANUS 79) the transitions which occur from season to season can be observed. Table 2 is a list of the XBT sections included in this report with the corresponding figure numbers (figure 16-31) of the location chart and section. Of note are the strong cold-core ring in early May 1980 (OCEANUS 79) and the thick "18° water" region in all sections.

Two XBT time series were made at Site L during the test cruises. A 25-hour time series in May 1980 (figure 32) shows very little internal tidal motion. The other time series, which is only 7 hr long (figure 33), was obtained in February 1981.

Table 2: A summary of the XBT sections made during the LOTUS engineering test cruises.

Figure Numbers	Vessel	Cruise Number	Date	Description
16-17	OCEANUS	79	2-3 May 1980	70°W, 39.1°-33.8°N
18-19	OCEANUS	79	7-8 May 1980	70°W, 39.7°-33°N
20-21	OCEANUS	85	3-4 Aug. 1980	70°W, 39.5°-34°N
22-23	KNORR	85	4-6 Dec. 1980	70°W, 39.4°-34.1°N
24-25	KNORR	87	26-28 Feb. 1981	70°W, 40°-33°N
26-27	KNORR	87	28 Feb.-3 Mar. 1981	70°W, 40°-33°N
28-29	OCEANUS	96	19-21 May 1981	70°W, 40.1°-33°N
30-31	OCEANUS	103	16-17 Sept. 1981	70°W, 37.8°-34.2°N

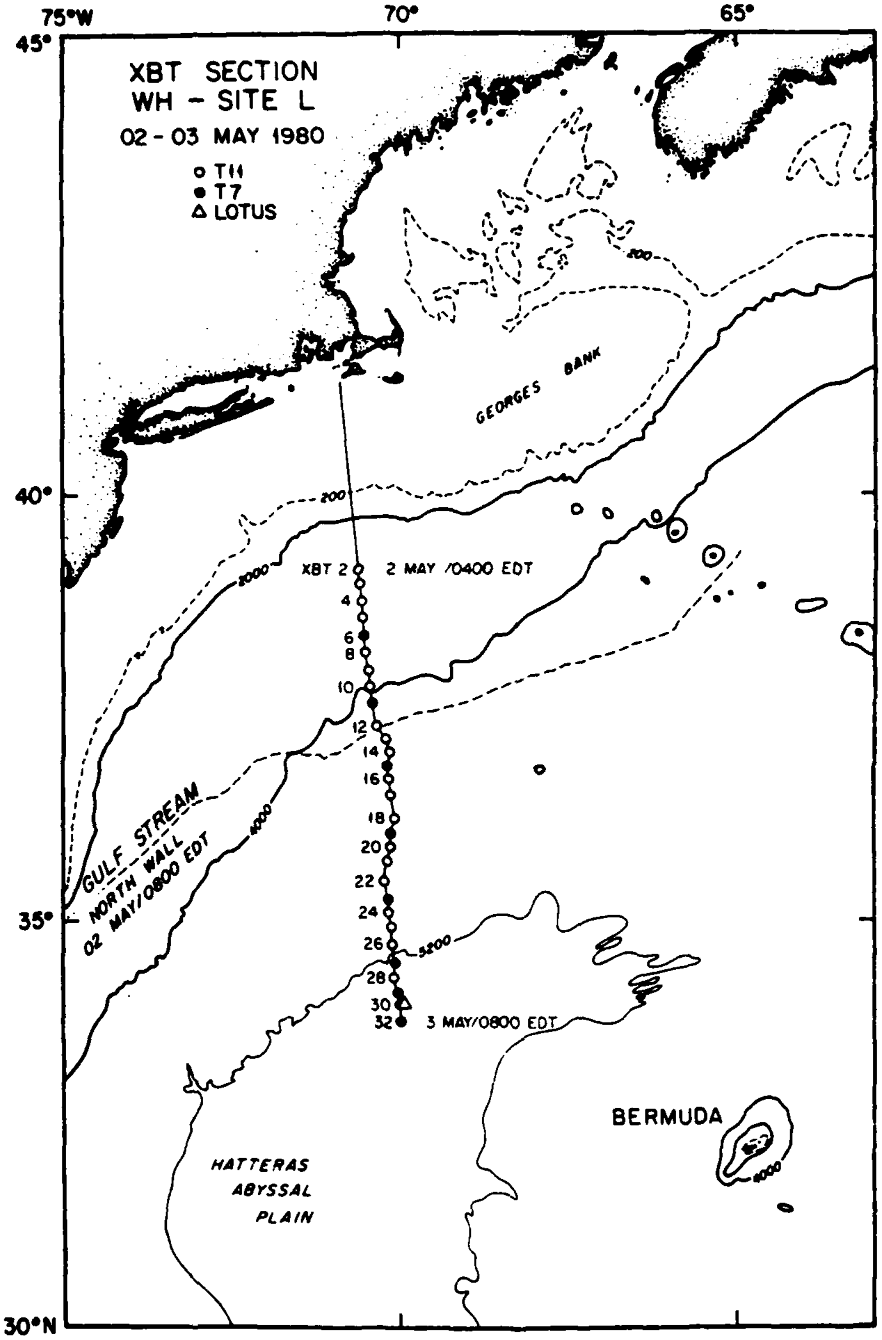

Figure 16: Chart showing the locations of the XBT's taken during OCEANUS cruise 79, 2-3 May 1980.

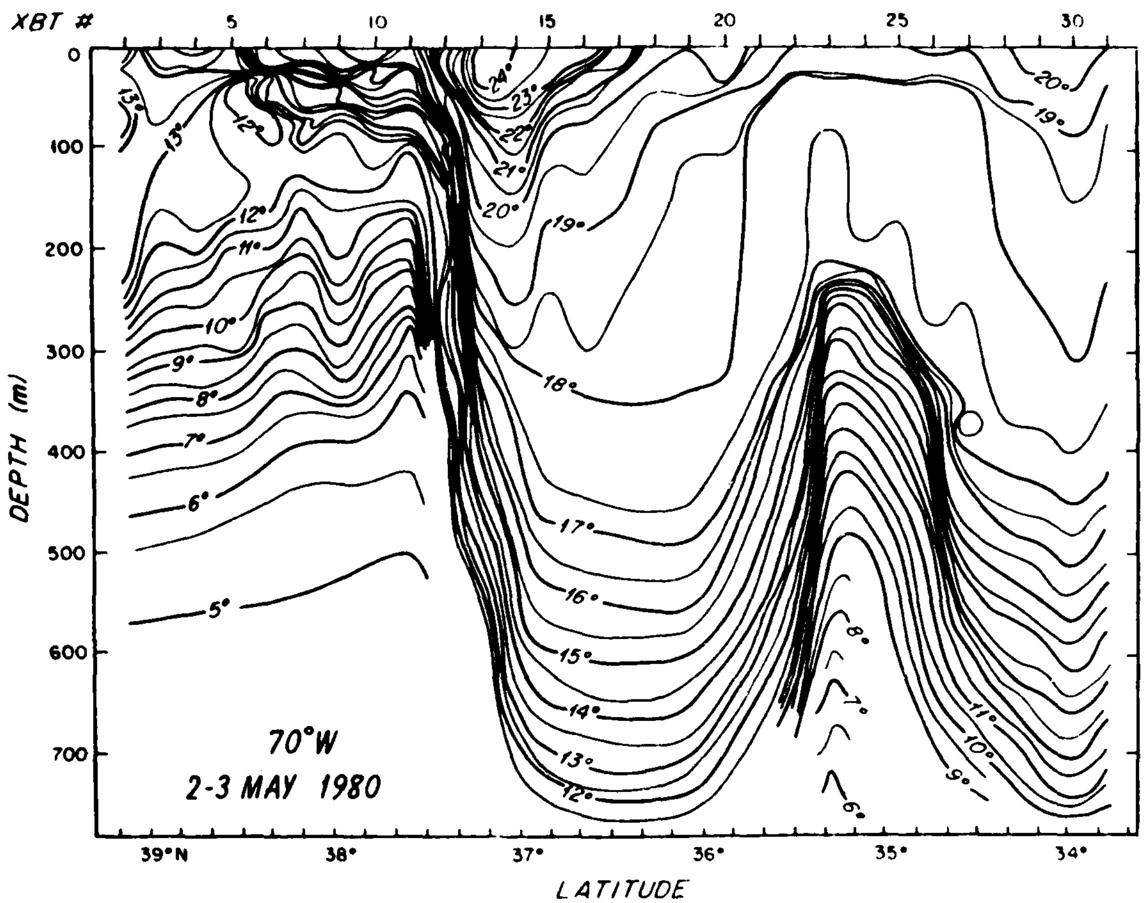

Figure 17: XBT section along 70°W between 39.1°N and 33.8°N, 2-3 May 1980.

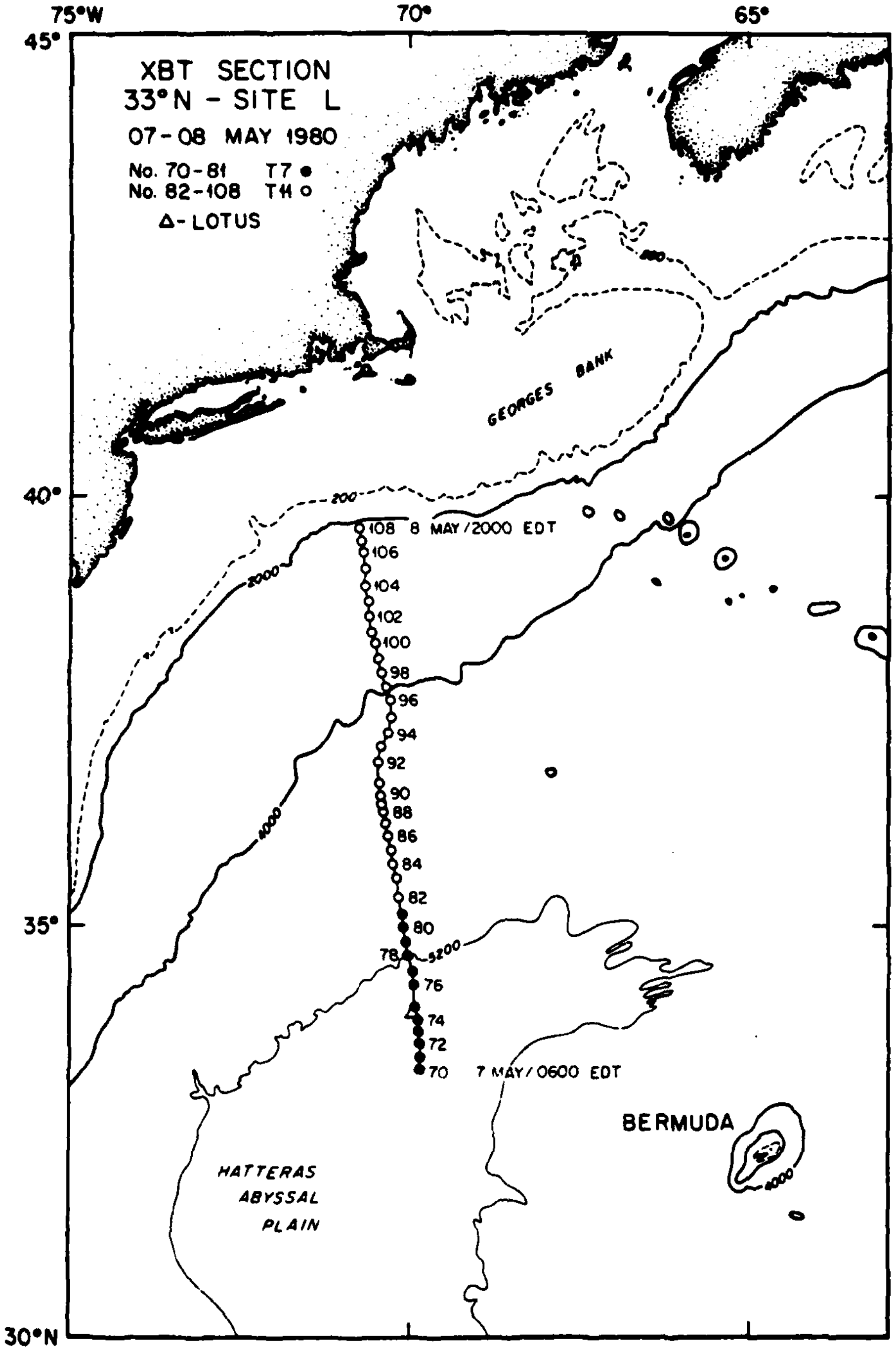

Figure 18: Chart showing the locations of the XBT's taken during OCEANUS cruise 79, 7-8 May 1980.

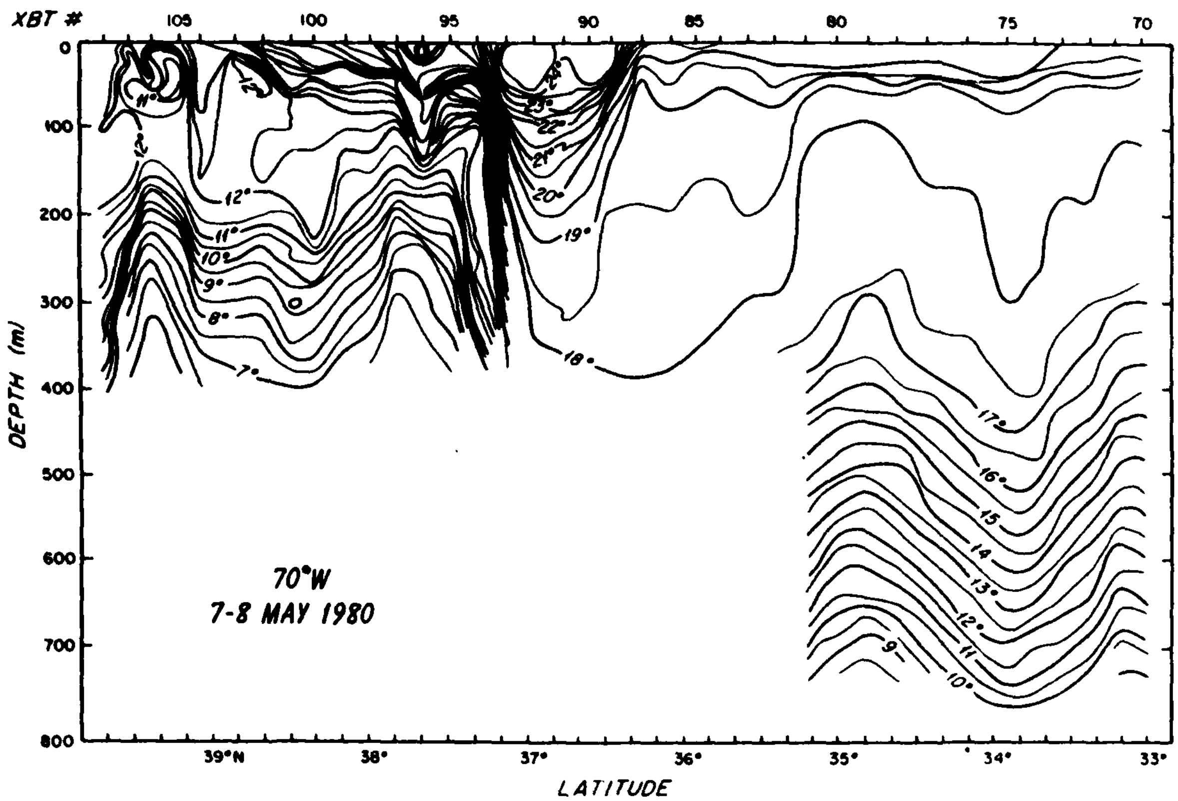

Figure 19: XBT section along 70°W between 39.7°N and 33°N, 7-8 May 1980.

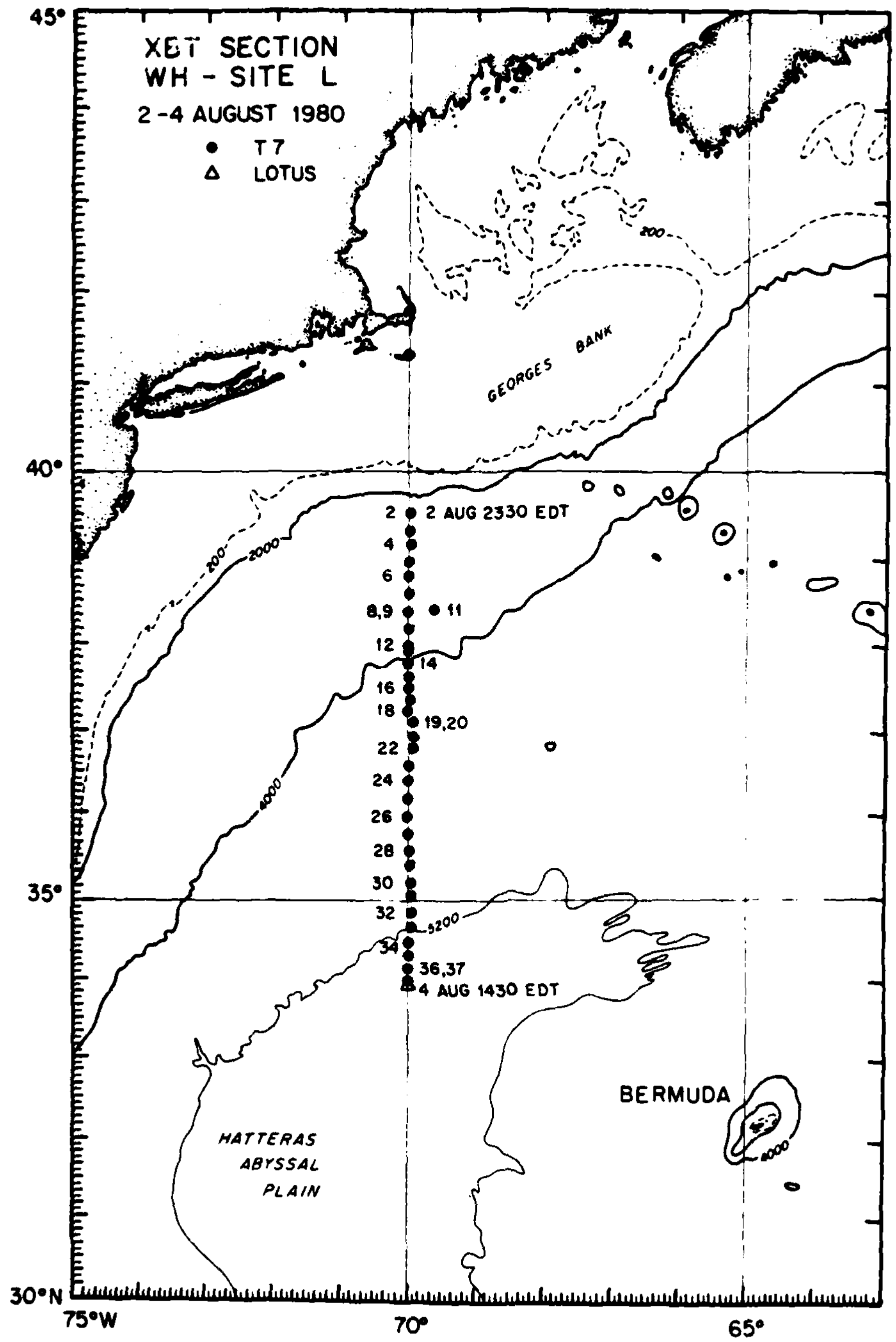

Figure 20: Chart showing the locations of the XBT's taken during OCEANUS cruise 85, 2-4 Aug. 1980.

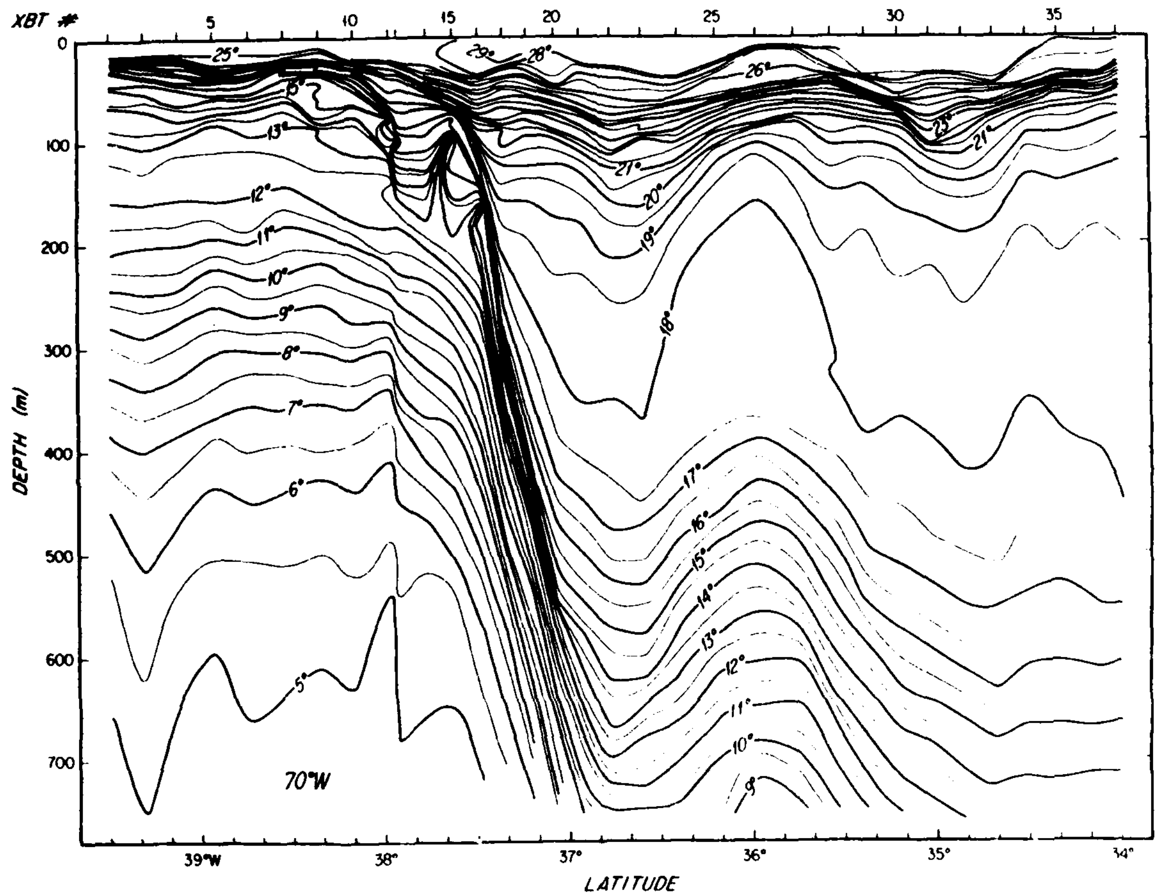

Figure 21: XBT section along 70°W between 39.5°N and 34°N, 2-4 Aug. 1980.

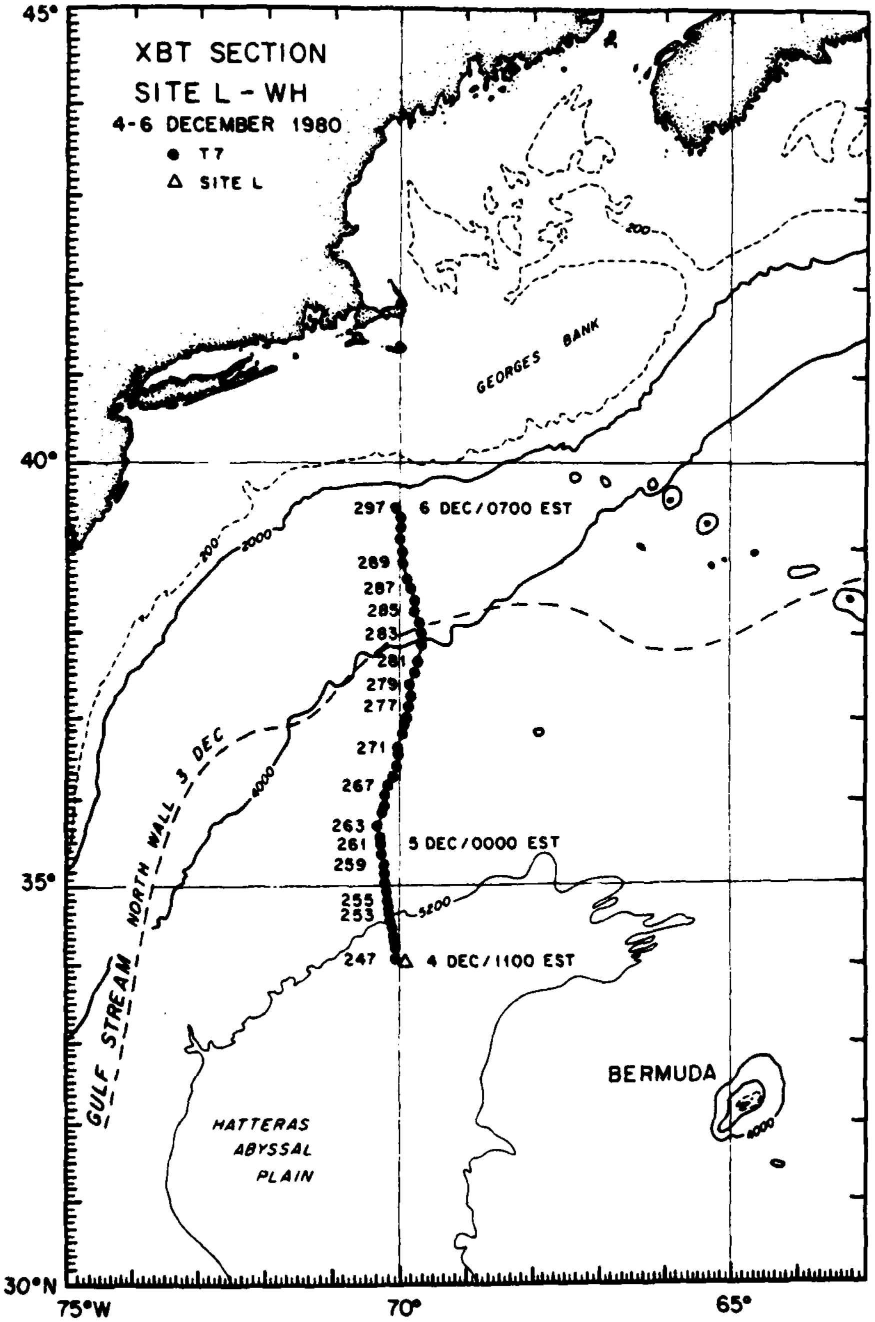

Figure 22: Chart showing the locations of the XBT's taken during KNORR 85, 4-6 Dec. 1980.

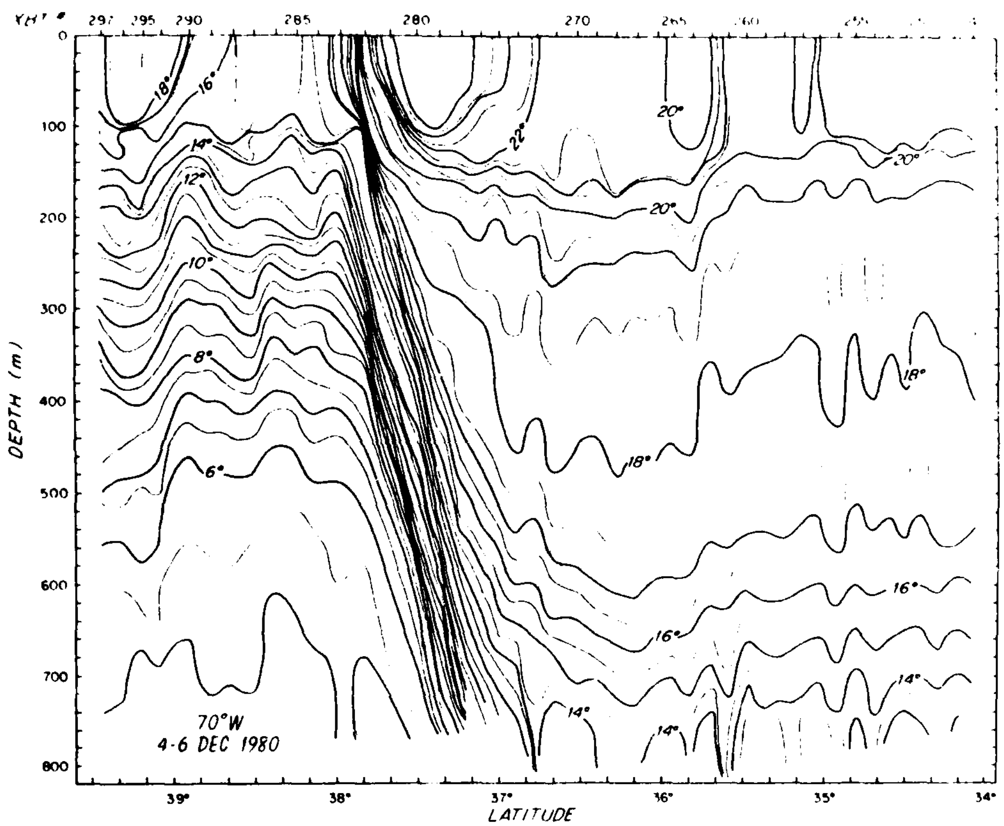

Figure 23: XBT section along 70°W between 39.4°N and 34.1°N, 4-6 Dec. 1980.

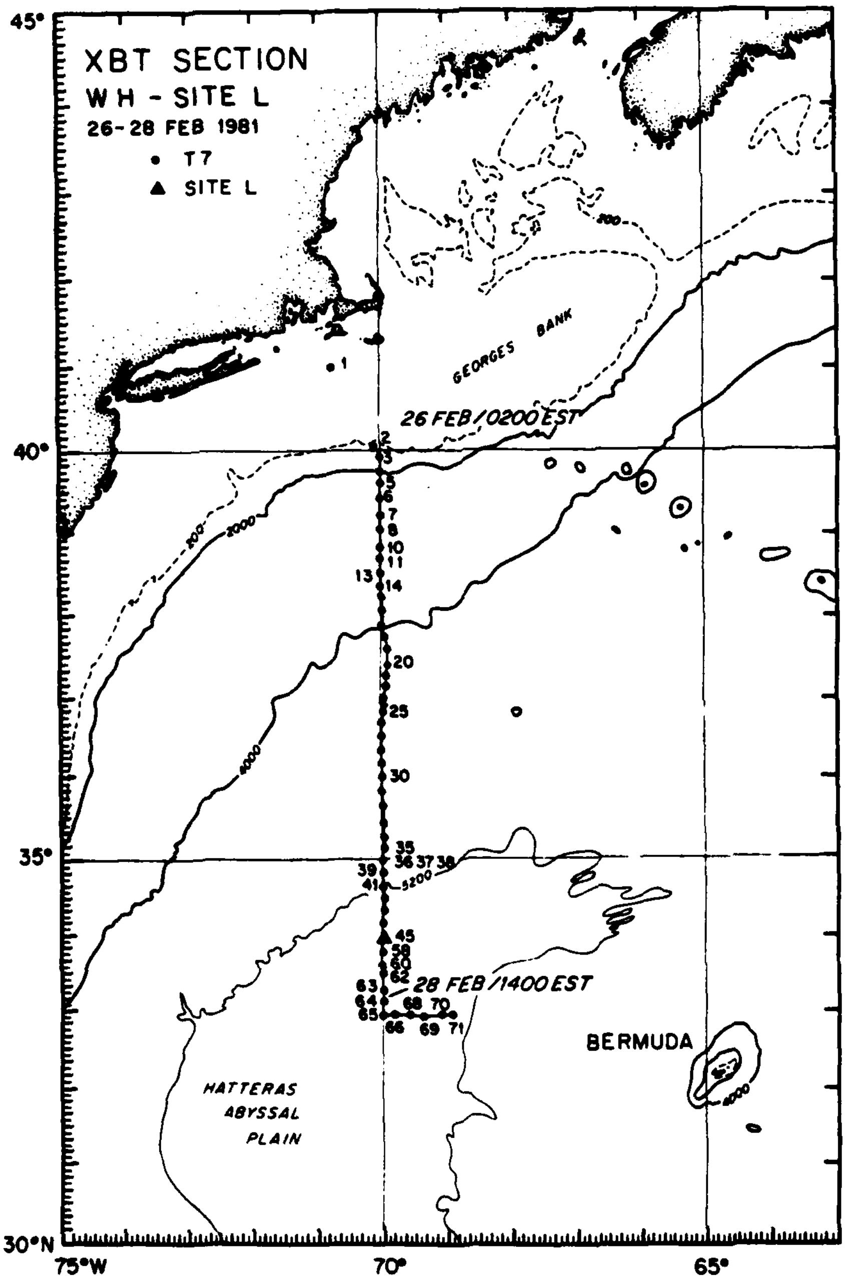

Figure 24: Chart showing the locations of the XBT's taken during KNORR 87, 26-28 Feb. 1981.

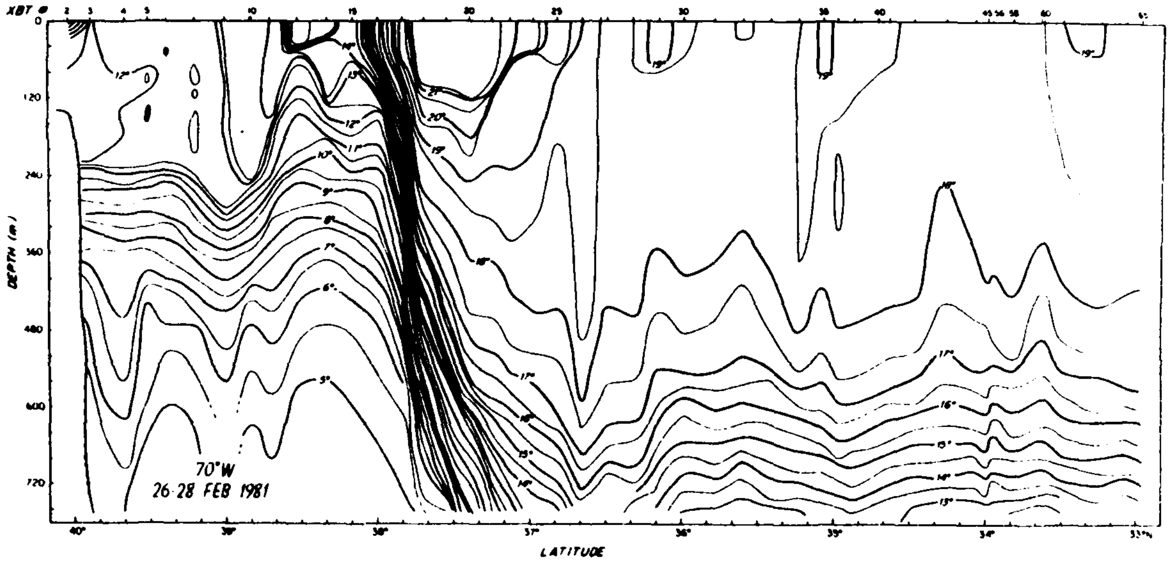

Figure 25: XBT section along 70°W between 40°N and 33°N, 26-28 Feb. 1981.

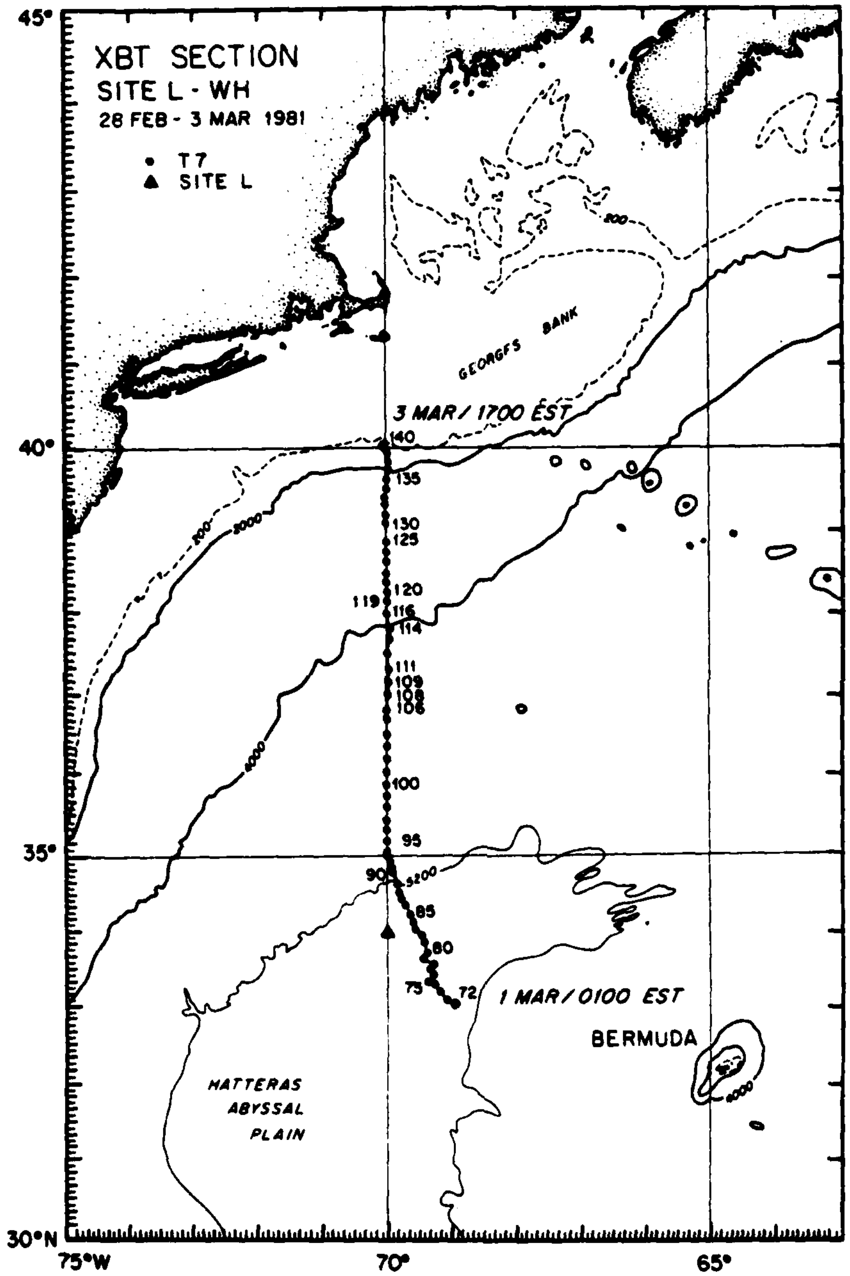

Figure 26: Chart showing the location of the XBT's taken during KNORR 87, 28 Feb. - 3 Mar. 1981.

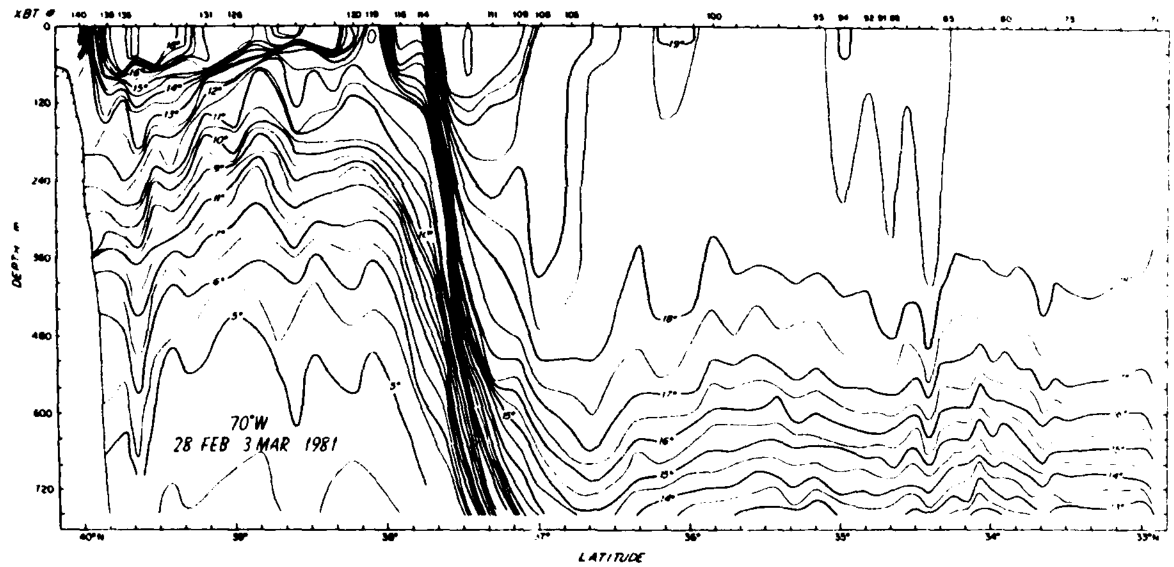

Figure 27: XBT section along 70°W between 40°N and 33°N, 28 Feb. - 3 Mar. 1981.

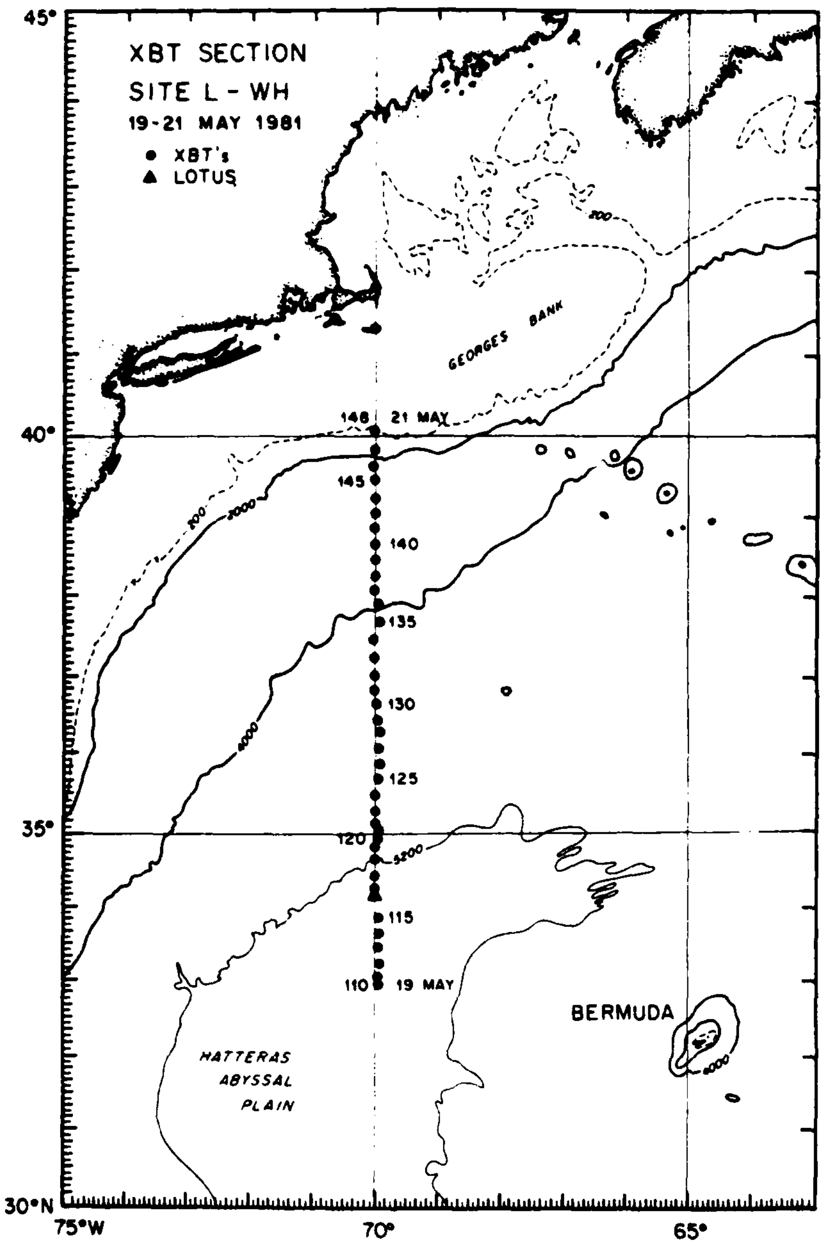

Figure 28: Chart showing the locations of the XBT's taken during OCEANUS 96, 19-21 May 1981.

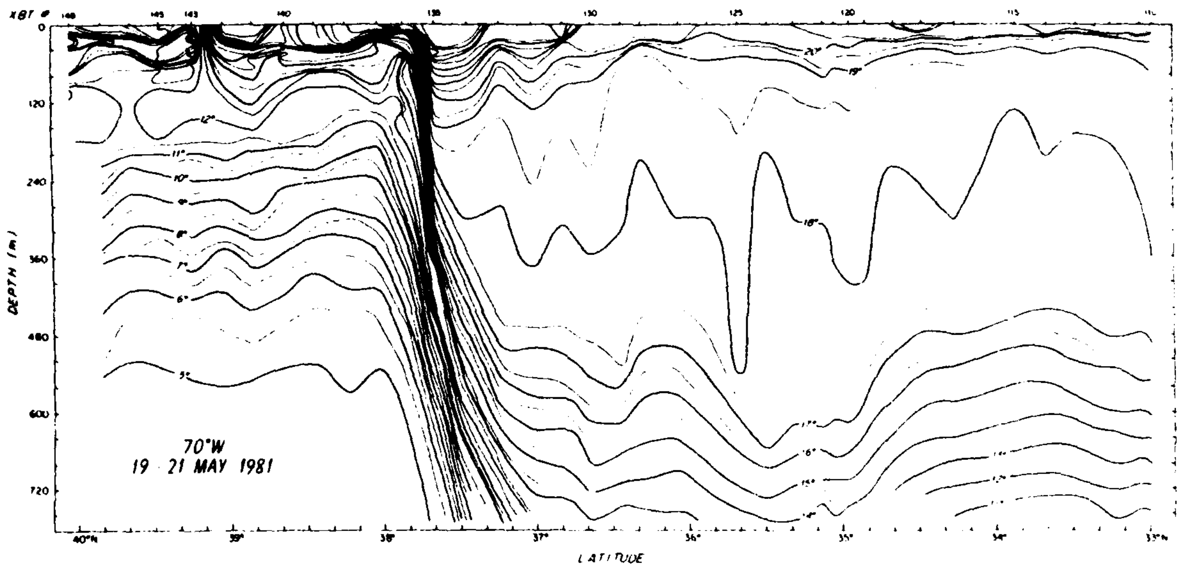

Figure 29: XBT section along 70°W between 40.1°N and 33°N, 19-21 May 1981.

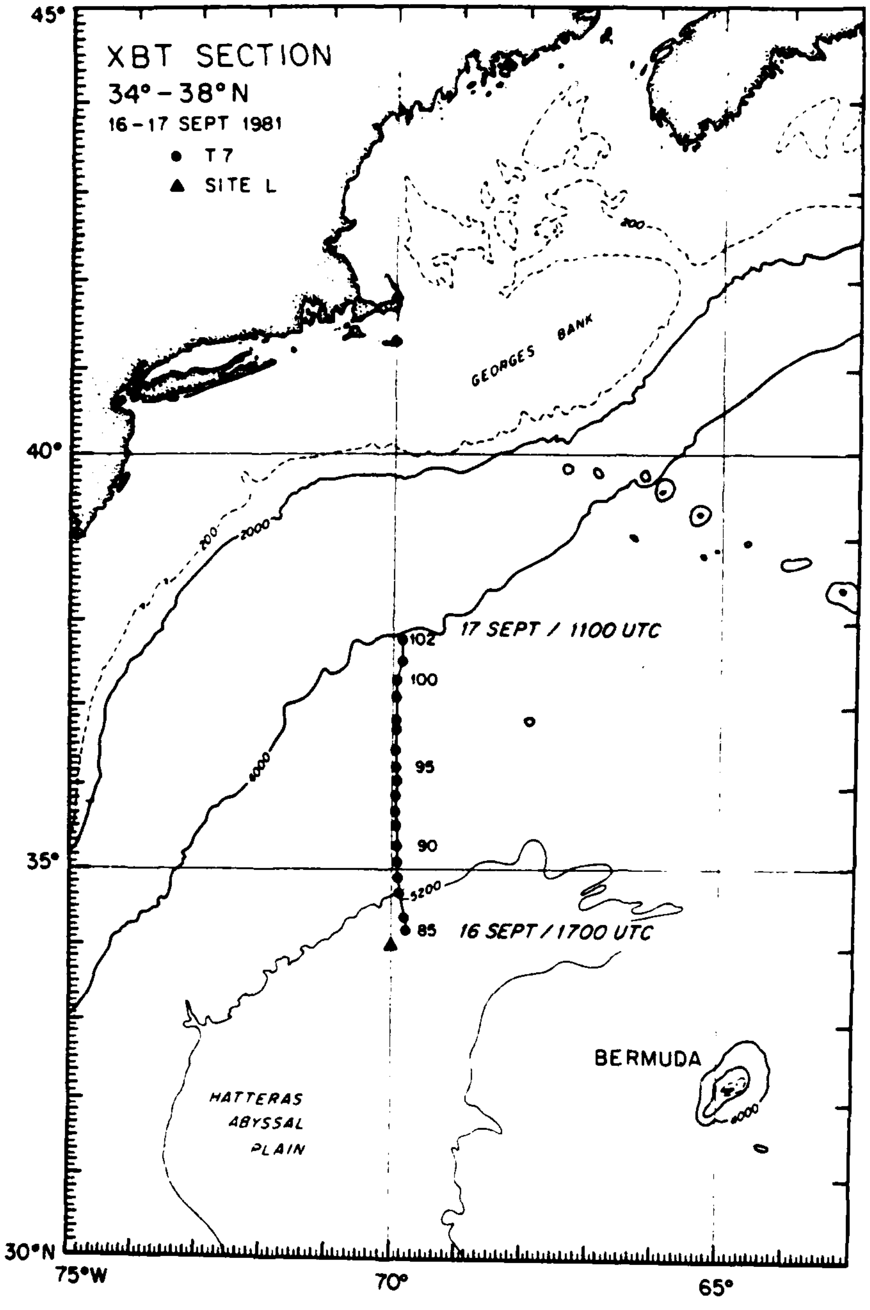

Figure 30: Chart showing the locations of the XBT's taken during OCEANUS 103, 16-17 Sept. 1981.

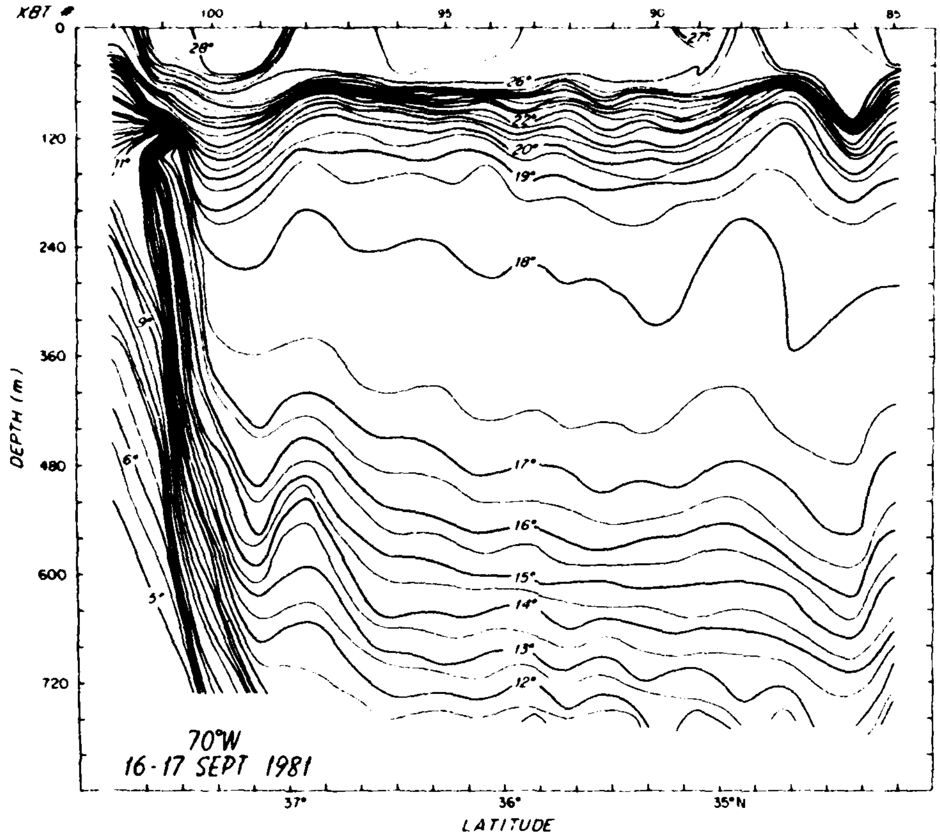

Figure 31: XBT section along 70°W between 37.8°N and 34.2°N, 16-17 Sept. 1981.

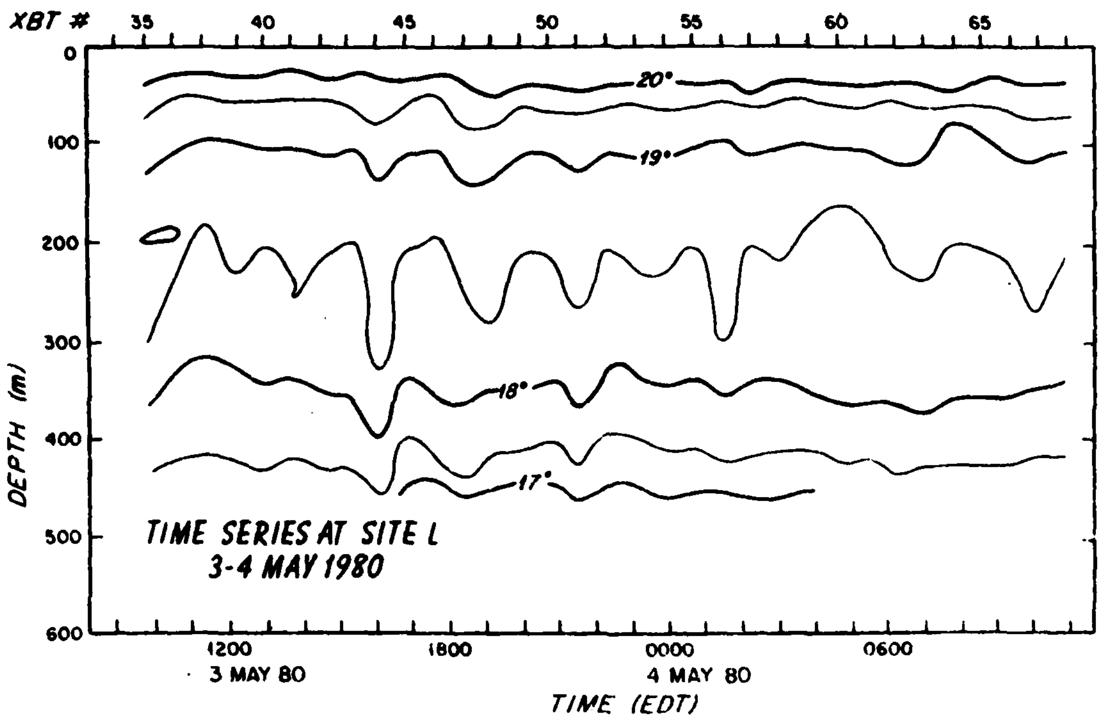

Figure 32: XBT time series from OCEANUS 79 at Site L, 3-4 May 1980.

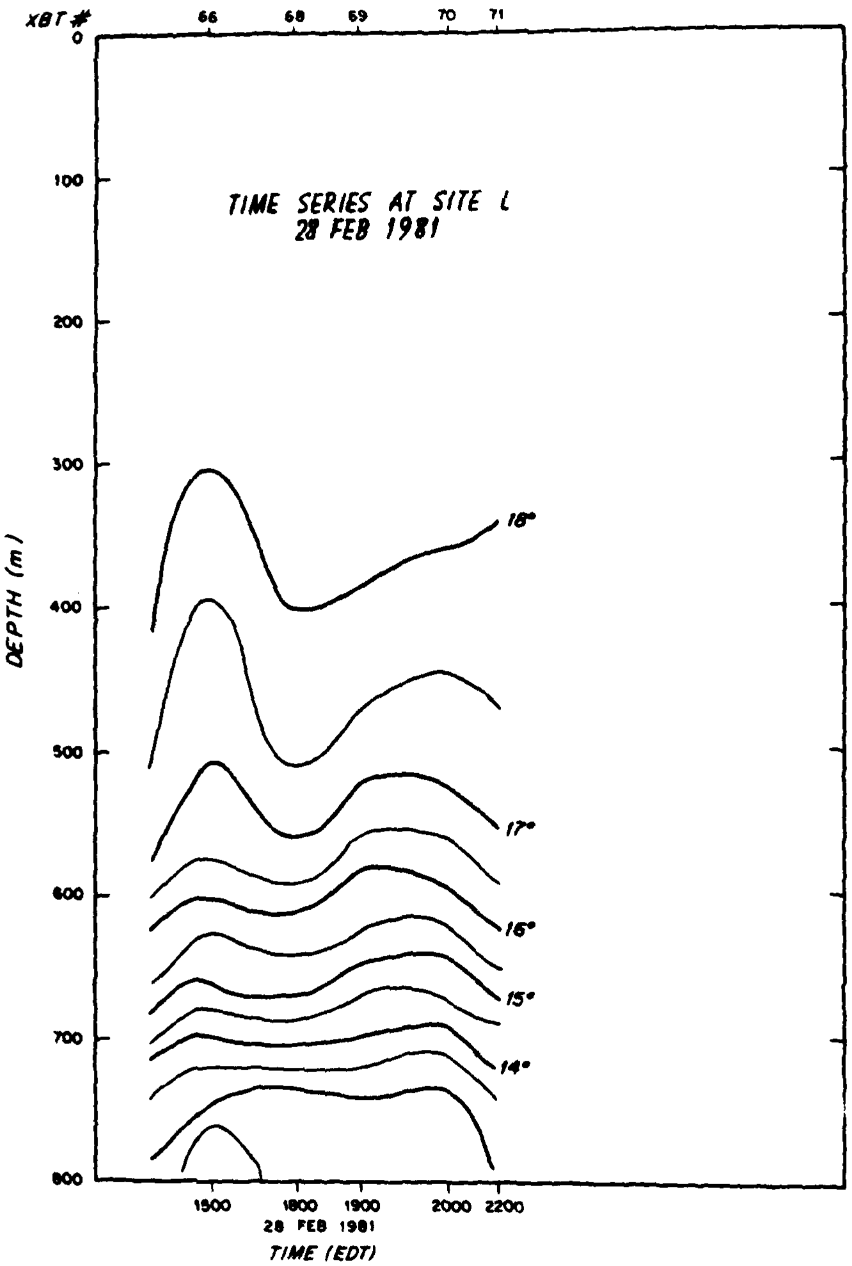

Figure 33: XBT time series from KNORR 87 at Site L, 28 Feb. 1981.

e. CTD Data

The LOTUS CTD program evolved considerably during the engineering test period. It began with the acquisition of a new Neil Brown Instrument Systems internal-recording CTD (CTD/IR). This CTD/IR is battery powered and has the capability to record its data on a cassette tape within the CTD/IR. Since there is no need for the conventional electromechanical cable the CTD/IR is lowered using the ship's hydro-wire. This however does not permit any real time output of data on-board ship. Depth information is obtained by monitoring the distance the instrument is from the bottom using a Benthos pinger (attached to the CTD/IR) in conjunction with a precision depth recorder (PDR).

The CTD/IR was first used during OCEANUS cruise number 85. Calibration water samples were obtained using Nansen bottles attached to the hydro-wire. This method proved to be awkward and difficult to interpret. With the experience gained from the first cruise a better calibration scheme was developed, modified and tested during the cruises that followed. In turn the quality of the calibration samples from later cruises improved.

The new sampling scheme, fashioned after a rosette sampler, was designed for use with the CTD/IR. It differs from the rosette sampler in that it is a simple messenger actuated system in which all the sample bottles close at the same time. The use of a messenger actuated system eliminates the need of any conducting cable and preserves the flexibility of the internally recording CTD which can be lowered using any standard hydrographic wire. The system consists of three 1.7 liter Nisken bottles attached to the pressure case of the CTD/IR. The bottles are tripped by a mechanism mounted above the CTD/IR on a small tripod. The hydro-wire passes through a hole in the tripping mechanism and is shackeled to a swivel attached to the end plate of the CTD/IR. Since the tripping mechanism is above the hydro-wire termination there are no obstructions in the way of the messenger. With the messenger impact the lanyards from the three Nisken bottles are released and all three bottles are closed at the same time and at the same depth as the CTD/IR. In order to obtain a time mark as to when the bottles closed, the Benthos Pinger is switched to a double ping rate when the bottles are tripped. The change in ping rate is detected using the ship's PDR. This not only gives an indication of the time when the samples are taken but also verifies that the messenger has reached the CTD/IR and has activated the tripping mechanism. Mechanical and operational details of the CTD/IR and its in situ calibration scheme can be found in Trask (1981).

The temperature and pressure CTD/IR data are taken directly from the instrument applying only the manufacturers calibration coefficients. The conductivity sensor is calibrated with the water samples collected at depth. Water sample salinities were determined using a Guildline "Autosal" salinometer. A conductivity calibration coefficient (cell factor, K) was determined for each CTD/IR cast based on a comparison of the water sample salinities and the corresponding CTD/IR calculated salinities. The salinity computations are based on the 1978 Practical Salinity Scale (Lewis and Perkins, 1978) as recommended by the Joint Panel on Oceanographic Tables and Standards (JPOTS).

The cell factor is the scaling factor the measured conductivity must be multiplied by to obtain the "true" conductivity. The proper value of K was determined by an iterative process in which the CTD/IR conductivity values (in the region where the water samples were taken) were multiplied by K which is adjusted until the calculated CTD/IR salinities and bottle salinities were matched within reasonable limits ($\pm$ .003 psu). The conductivity values of the entire cast were then multiplied by the appropriate K to obtain the "true" conductivities.

Preliminary processing of the CTD/IR data was accomplished using a Hewlett-Packard 85 desk-top computer. The preliminary processing involves taking the raw down-cast data from cassette and applying the appropriate calibration coefficients, editing wild points, and applying a sensor time lag correction. This correction is applied to the pressure and conductivity data since these sensors respond to sudden changes considerably faster than does the platinum temperature sensor. The recursive filter, which in effect slows down the conductivity and pressure sensors to match the temperature sensor, is described in Millard (1981). The data were then pressure averaged over a two decibar pressure range. Salinities were calculated and then the averaged pressure, temperature, conductivity, and salinity were stored on flexible disc. The pressure averaged data are then available for computing a number of other oceanographic variables.

Data Presentation

During each engineering test cruise at least one CTD/IR station was made in the LOTUS area. All of the CTD/IR stations are not presented in this report. Many of the stations made during individual cruises are in close proximity to each other. In those instances a single representative station has been selected for presentation here. Several cruises had sufficient time to make some stations throughout the 2 degree square LOTUS area. Where available those stations which were made at the intersection of whole degrees of latitude and longitude in the LOTUS area are also presented for spatial considerations. The presentation consists of tabular listings of pressure (PRESS) in decibars, in situ temperature (TEMP) in degrees centigrade, salinity (SALIN) in practical salinity units, sigma-t in kg/m^3, sound speed (SSPEED) in meters/second, dynamic height (DYNHGT) in dynamic meters, potential temperature (POTEMP) in degrees centigrade, potential temperature gradient (POTGRD) in millidegrees centigrade/decibar, potential density (POTDEN) in kg/m^3 and Brunt Väisälä frequency (BR-V) in cycles per hour at standard pressures along with graphical profiles of potential temperature and salinity. The heading of the listings include an abbreviated ship name (OC = OCEANUS and KN = KNORR) and cruise number, CTD number, year, day of year and time, latitude and longitude and the depth of the water.

Table 3 summarizes the LOTUS CTD/IR work conducted during the engineering test period. The page numbers refer to the CTD sections corresponding to each cruise.

As a graphic summary of the seasonal variability of potential temperature and salinity at 34°N, 70°W, a composite plot of four CTD/IR stations, one from each season, are presented in figure 50.

Table 3: A summary of the CTD/IR work conducted during the LOTUS engineering test period.

CRUISE	DATE	No. of CTDs in LOTUS area	Page No.
OCEANUS 85	Aug. 1980	5	60
KNORR 85	Nov. 1980	1	64
KNORR 87	Feb. 1981	10	68
OCEANUS 96	May 1981	7	78
OCEANUS 103	Sept. 1981	3	86

OCEANUS 85

AUGUST 1980

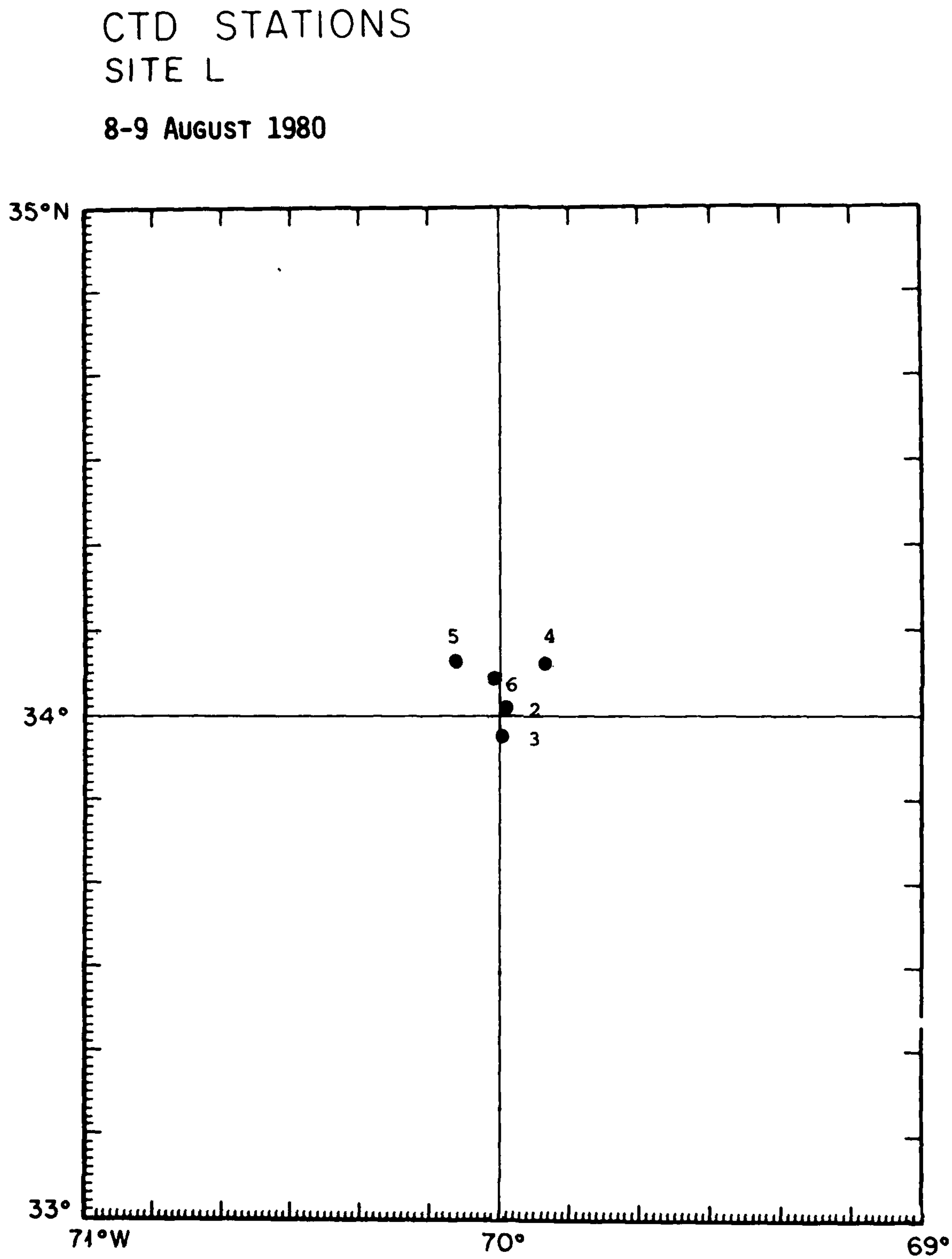

Figure 34: Chart showing the locations of CTD stations made during OCEANUS 85, Aug. 1980.

OC 85 CTD 002 1980 221 1313Z 34 00.26N 69 59.85W

PRESS dbar	TEMP °C	SALIN psu	POTEMP °C	POTGRD m°C/db	SIGMA-t kg/m**3	POTDEN kg/m**3	BR-V cph	SSPEED m/s	DYNHGT dyn m
2.	27.572	36.208	27.571	0.00	23.464	23.446	0.00	1541.7	0.0000
6.	27.556	36.205	27.555	9.99	23.467	23.449	4.42	1541.7	.0186
10.	27.322	36.171	27.319	113.79	23.517	23.499	10.90	1541.2	.0347
16.	26.288	36.145	26.284	99.11	23.827	23.810	10.54	1538.9	.0613
20.	26.092	36.190	26.087	54.78	23.923	23.906	7.56	1538.6	.0762
26.	25.802	36.204	25.796	85.28	24.024	24.008	11.57	1538.0	.0998
30.	25.061	36.268	25.054	266.87	24.301	24.285	14.37	1536.4	.1160
36.	23.991	36.376	23.983	203.92	24.705	24.690	13.73	1534.0	.1374
50.	21.878	36.546	21.868	74.57	25.445	25.432	10.30	1529.1	.1770
66.	20.974	36.582	20.961	82.18	25.723	25.711	5.94	1527.0	.2165
75.	20.535	36.599	20.520	31.13	25.856	25.844	7.32	1526.0	.2372
100.	19.547	36.601	19.528	8.30	26.119	26.109	4.40	1523.7	.2873
126.	18.896	36.594	18.874	23.13	26.283	26.274	3.44	1522.3	.3352
150.	18.667	36.578	18.640	11.22	26.330	26.321	2.06	1522.0	.3776
200.	18.483	36.568	18.448	.72	26.369	26.363	1.38	1522.3	.4645
250.	18.390	36.561	18.346	2.43	26.387	26.383	1.14	1522.8	.5516
300.	18.276	36.552	18.223	2.52	26.406	26.407	1.25	1523.3	.6379
350.	18.147	36.535	18.085	1.59	26.428	26.428	1.19	1523.8	.7243
400.	18.052	36.525	17.982	2.30	26.443	26.446	1.13	1524.3	.8102
450.	17.766	36.477	17.688	8.63	26.478	26.482	1.69	1524.3	.8964
500.	17.508	36.441	17.422	2.66	26.514	26.520	1.48	1524.3	.9814
550.	17.126	36.371	17.033	5.88	26.553	26.560	1.83	1523.9	1.0650
600.	16.539	36.270	16.440	9.21	26.616	26.624	2.16	1522.8	1.1475
650.	15.740	36.132	15.636	21.76	26.695	26.703	2.13	1521.1	1.2268
700.	14.806	35.971	14.698	14.59	26.780	26.788	2.67	1518.8	1.3029
750.	13.770	35.807	13.660	6.57	26.876	26.883	2.54	1516.1	1.3743
800.	12.630	35.632	12.519	10.96	26.974	26.980	2.76	1512.9	1.4416
900.	10.383	35.332	10.272	14.25	27.163	27.165	2.19	1506.5	1.5617
1000.	8.354	35.141	8.245	27.37	27.350	27.348	2.82	1500.5	1.6635
1100.	6.849	35.092	6.740	5.48	27.533	27.527	2.19	1496.3	1.7451
1200.	5.846	35.066	5.735	7.55	27.645	27.639	1.88	1494.0	1.8121
1300.	5.238	35.048	5.123	6.97	27.707	27.699	1.39	1493.2	1.8703
1400.	4.886	35.033	4.765	3.79	27.736	27.729	.89	1493.4	1.9244
1500.	4.650	35.025	4.522	1.16	27.757	27.750	.93	1494.1	1.9767
1600.	4.412	35.006	4.278	1.07	27.768	27.762	.83	1494.8	2.0275
1800.	4.136	34.994	3.986	4.06	27.788	27.783	.67	1497.0	2.1272
2000.	3.971	34.992	3.804	.10	27.804	27.800	.58	1499.6	2.2258
2200.	3.757	34.986	3.574	-.25	27.822	27.819	.73	1502.1	2.3231
2400.	3.590	34.985	3.389	.98	27.838	27.836	.64	1504.8	2.4186
2500.	3.505	34.979	3.296	1.63	27.841	27.840	.56	1506.1	2.4658
2600.	3.427	34.975	3.209	.67	27.846	27.845	.60	1507.4	2.5129
2800.	3.233	34.962	2.998	.97	27.854	27.855	.63	1510.0	2.6069
3000.	3.088	34.952	2.835	.19	27.861	27.862	.48	1512.8	2.6998
3200.	2.937	34.942	2.666	1.01	27.866	27.869	.62	1515.5	2.7927
3400.	2.792	34.933	2.503	.93	27.872	27.876	.51	1518.3	2.8840
3600.	2.677	34.926	2.369	.64	27.877	27.882	.57	1521.2	2.9748
3800.	2.569	34.921	2.242	1.18	27.882	27.888	.50	1524.2	3.0650
4000.	2.482	34.915	2.134	.01	27.885	27.893	.47	1527.3	3.1550
4200.	2.409	34.910	2.040	1.17	27.888	27.897	.39	1530.4	3.2447
4400.	2.375	34.904	1.984	.40	27.885	27.896	.29	1533.7	3.3357
4600.	2.352	34.899	1.937	.74	27.884	27.896	.31	1537.1	3.4281
4800.	2.340	34.896	1.901	.14	27.882	27.896	.28	1540.5	3.5218
5000.	2.335	34.892	1.871	.16	27.880	27.896	.26	1543.9	3.6177
5200.	2.334	34.890	1.845	-.03	27.878	27.896	.27	1547.4	3.7151
5400.	2.293	34.880	1.779	.02	27.873	27.893	0.00	1550.7	3.8151

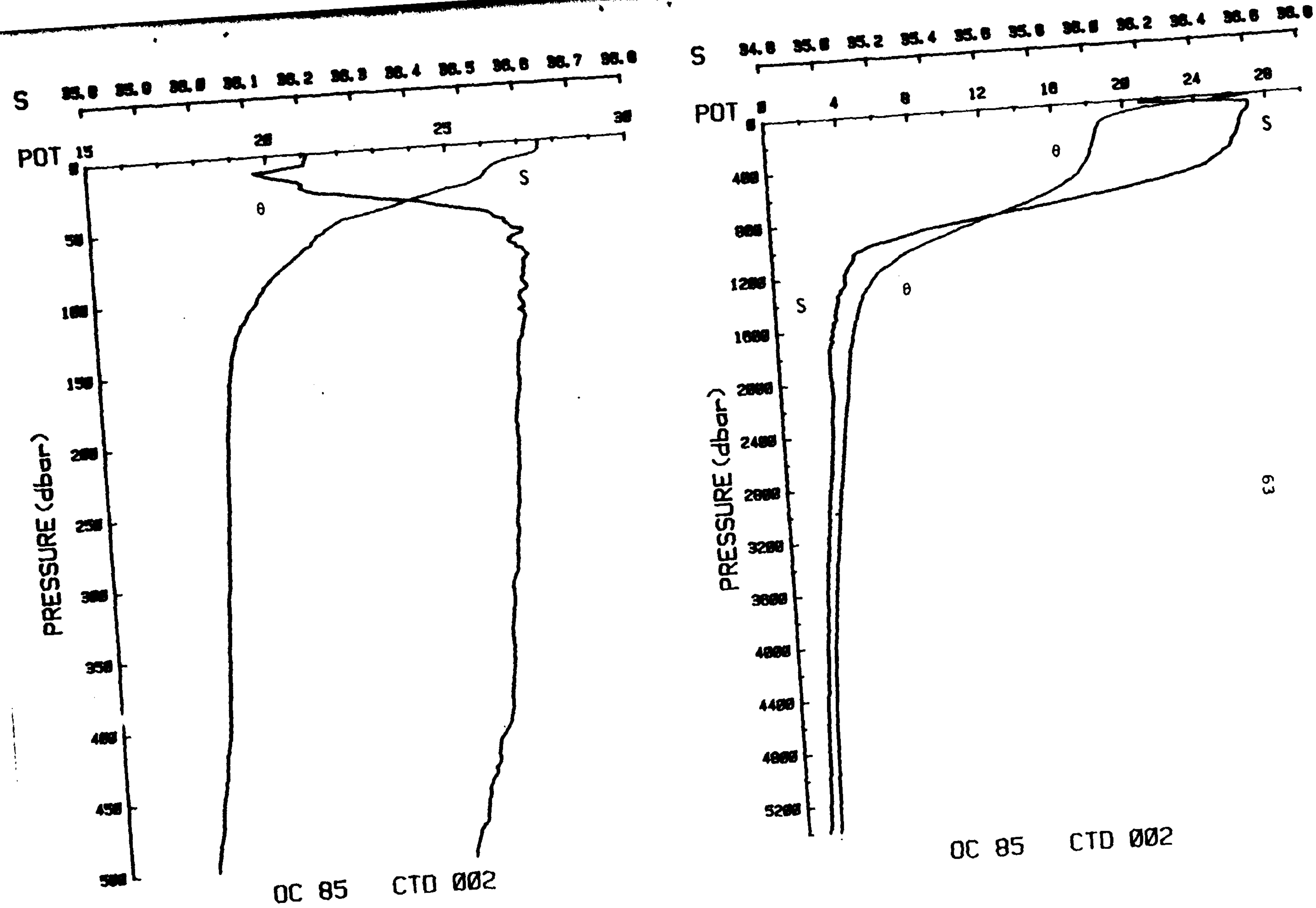

Figure 35: Profiles of potential temperature and salinity from OCEANUS 85, CTD number 2, 8 Aug. 1980.

KNORR 85

DECEMBER 1980

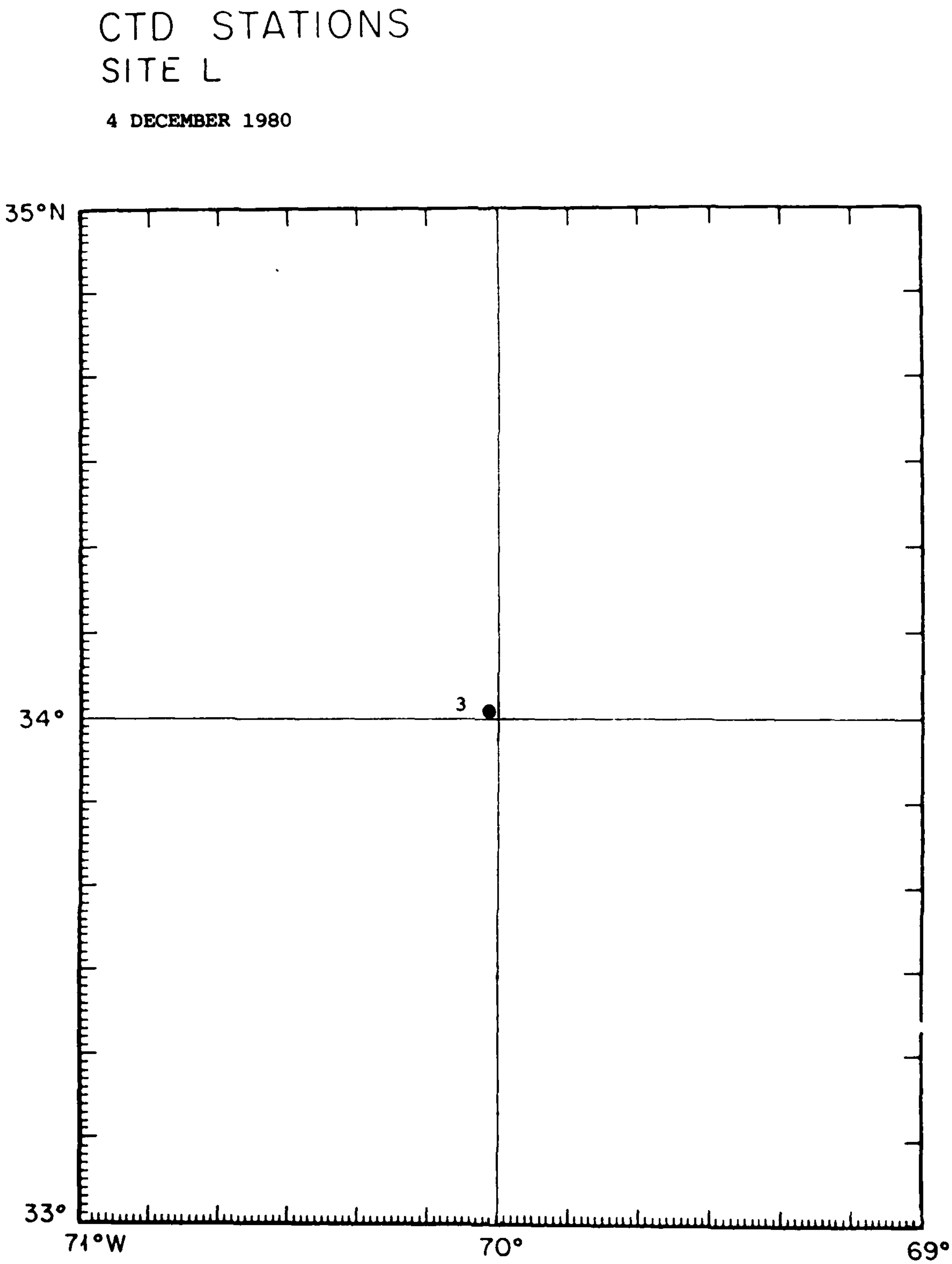

Figure 36: Chart showing the locations of CTD stations made during KNORR 85, Dec. 1980.

KN 85 CTD 003 1980 339 1155Z 34 00.83N 70 01.43W

PRESS dbar	TEMP °C	SALIN psu	POTEMP °C	POTGRD m°C/db	SIGMA t kg/m**3	POTDEN kg/m**3	BR-V cph	SSPEED m/s	DYNHGT dyn m
2.	21.116	36.553	21.116	0.00	25.662	25.646	0.00	1526.3	0.0000
6.	21.133	36.548	21.132	-1.36	25.654	25.638	-1.93	1526.4	.0096
10.	21.139	36.547	21.138	.30	25.651	25.636	-.79	1526.4	.0183
16.	21.140	36.548	21.137	.66	25.651	25.636	.59	1526.5	.0318
20.	21.140	36.548	21.136	-.84	25.651	25.637	-.46	1526.6	.0416
26.	21.145	36.547	21.140	-1.13	25.650	25.635	1.00	1526.7	.0562
30.	21.150	36.547	21.145	-.91	25.648	25.634	-.70	1526.8	.0655
36.	21.149	36.547	21.143	.39	25.648	25.635	.71	1526.9	.0800
50.	21.151	36.547	21.142	.49	25.648	25.635	.16	1527.2	.1131
66.	21.156	36.547	21.143	.94	25.647	25.634	.63	1527.4	.1513
76.	21.154	36.547	21.140	.07	25.647	25.635	.25	1527.6	.1750
100.	21.128	36.549	21.109	14.09	25.656	25.646	4.32	1527.9	.2318
126.	19.486	36.607	19.464	16.53	26.140	26.131	4.29	1523.9	.2860
150.	19.026	36.590	19.000	7.53	26.246	26.238	3.04	1523.0	.3310
200.	18.551	36.560	18.516	3.78	26.345	26.339	1.92	1522.5	.4198
250.	18.349	36.545	18.305	4.19	26.385	26.381	1.43	1522.7	.5064
300.	18.186	36.529	18.134	3.79	26.414	26.412	1.57	1523.0	.5929
350.	17.995	36.508	17.934	2.91	26.445	26.445	1.33	1523.3	.6788
400.	17.772	36.476	17.703	6.29	26.476	26.478	1.57	1523.4	.7640
450.	17.581	36.452	17.504	6.38	26.505	26.508	1.53	1523.7	.8484
500.	17.360	36.415	17.275	4.77	26.530	26.536	1.74	1523.8	.9318
550.	16.812	36.317	16.721	10.73	26.587	26.594	2.25	1522.9	1.0148
600.	16.140	36.200	16.043	11.73	26.655	26.662	2.22	1521.6	1.0954
650.	15.391	36.071	15.289	7.58	26.727	26.735	2.15	1519.9	1.1725
700.	14.477	35.918	14.372	11.68	26.811	26.818	2.46	1517.7	1.2467
750.	13.613	35.782	13.506	12.65	26.889	26.896	2.38	1515.5	1.3167
800.	12.726	35.653	12.615	15.67	26.971	26.977	2.52	1513.3	1.3837
900.	10.538	35.369	10.426	16.73	27.165	27.167	2.64	1507.1	1.5048
1000.	8.590	35.178	8.480	12.90	27.343	27.341	2.35	1501.4	1.6067
1100.	7.129	35.086	7.018	16.21	27.489	27.485	2.47	1497.4	1.6921
1200.	5.837	35.051	5.776	4.19	27.629	27.622	1.90	1494.1	1.7621
1300.	5.210	35.032	5.095	5.77	27.697	27.689	1.45	1493.1	1.8315
1400.	4.879	35.026	4.758	1.31	27.731	27.724	1.16	1493.4	1.8763
1500.	4.661	35.018	4.573	3.20	27.750	27.743	.87	1494.1	1.9292
1600.	4.430	35.002	4.296	4.19	27.763	27.756	.77	1494.8	1.9806
1800.	4.147	34.986	3.997	1.48	27.781	27.776	.64	1497.0	2.0819
2000.	3.965	34.983	3.798	.19	27.798	27.794	.61	1499.6	2.1816
2200.	3.809	34.980	3.625	1.39	27.812	27.809	.63	1502.3	2.2806
2400.	3.638	34.978	3.437	.26	27.827	27.826	.64	1504.9	2.3784
2500.	3.550	34.974	3.339	1.92	27.833	27.832	.66	1506.3	2.4270
2600.	3.471	34.972	3.253	1.25	27.839	27.839	.66	1507.6	2.4753
2800.	3.277	34.961	3.041	.69	27.849	27.850	.68	1510.2	2.5707
3000.	3.118	34.952	2.865	1.54	27.857	27.859	.59	1512.9	2.6649
3200.	2.952	34.942	2.681	.69	27.865	27.868	.63	1515.6	2.7581
3400.	2.780	34.932	2.492	1.33	27.872	27.876	.59	1518.3	2.8500
3600.	2.640	34.923	2.333	1.11	27.878	27.883	.60	1521.1	2.9407
3800.	2.522	34.915	2.125	.38	27.881	27.887	.47	1524.0	3.0300
4000.	2.436	34.909	2.090	.68	27.885	27.892	.44	1527.1	3.1191
4[illegible].	2.377	34.904	2.005	.51	27.886	27.894	.39	1530.3	3.2067
4400.	2.341	34.900	1.950	.24	27.885	27.895	.31	1533.6	3.2920
4600.	2.324	34.895	1.910	.19	27.883	27.895	.23	1536.9	3.3906
4900.	2.319	34.892	1.981	.06	27.881	27.895	.23	1540.4	3.4844
5000.	2.317	34.889	1.854	.20	27.878	27.894	.24	1541.[illegible]	[illegible]

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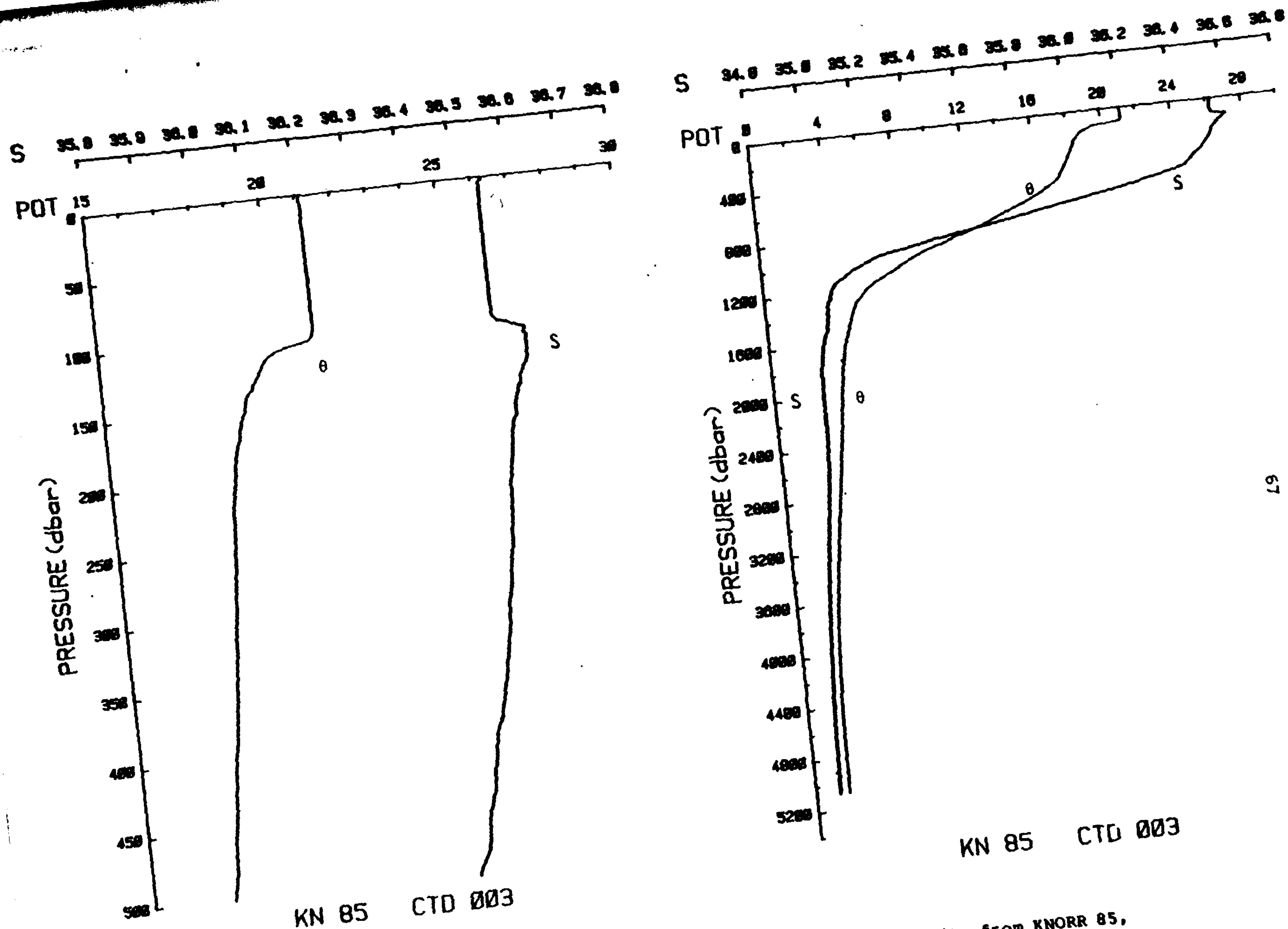


Figure 37: Profiles of potential temperature and salinity from KNORR 85, CTD number 3, 4 Dec. 1980.

KNORR 87

FEBRUARY - MARCH 1981

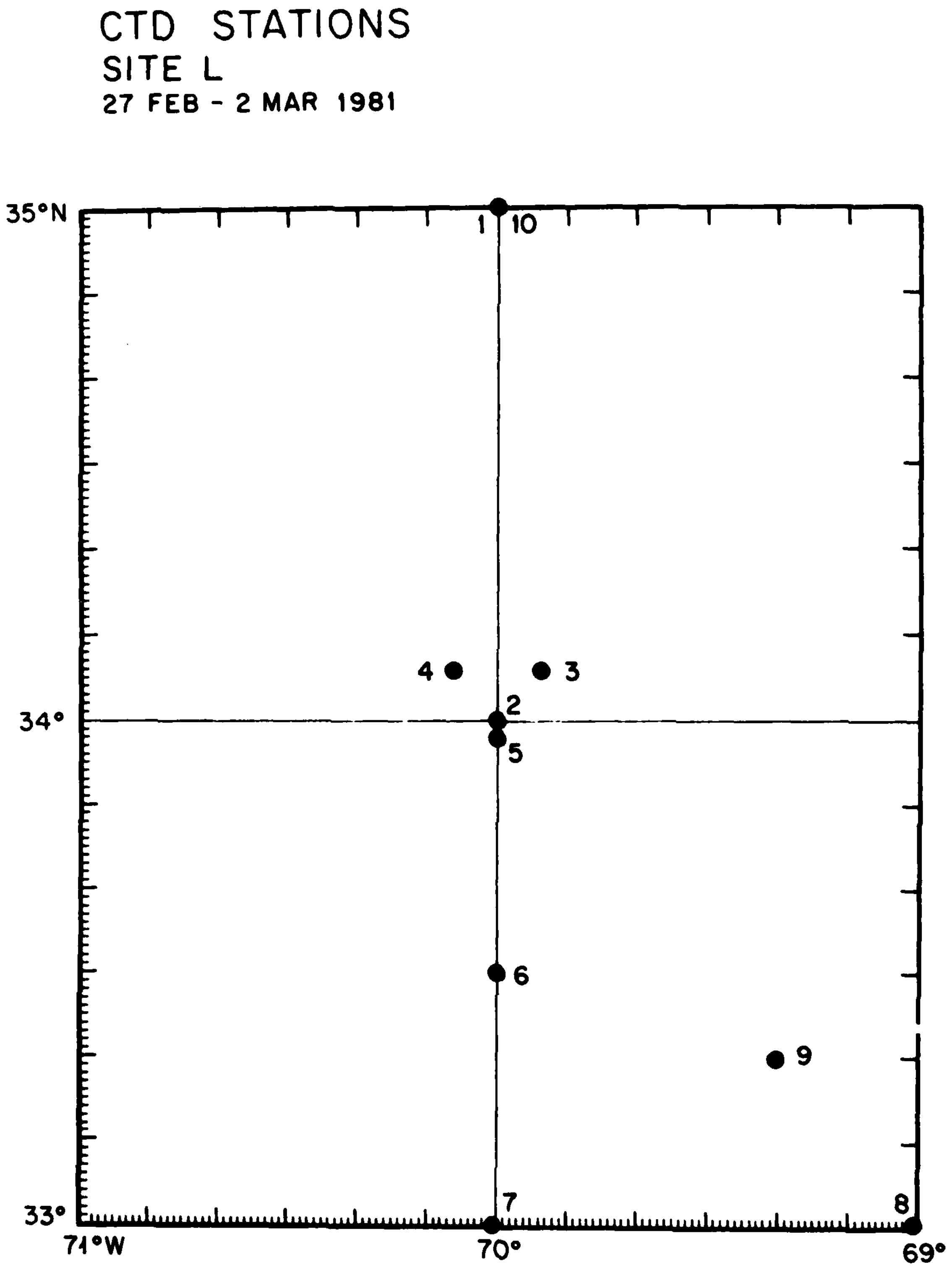


Figure 38: Chart showing the locations of CTD stations made during KNORR 87, Feb. 1981.

KN 87 CTD 002 1981 058 2032Z 33 59.99N 69 59.76W

PRESS dbar	TEMP ^{o}C	SALIN psu	POTEMP ^{o}C	POTGRD $m^{o}C/db$	SIGMA-t kg/m**3	POTDEN kg/m**3	BR-V cph	SSPEED m/s	DYNHGT dyn m
2.	18.444	36.550	18.444	0.00	26.365	26.350	0.00	1518.9	0.0000
6.	18.443	36.550	18.443	2.15	26.365	26.350	-1.17	1518.9	.0063
10.	18.457	36.550	18.455	-2.03	26.361	26.347	.35	1519.0	.0128
16.	18.446	36.550	18.444	.14	26.364	26.349	-.27	1519.1	.0234
20.	18.448	36.550	18.444	-.29	26.363	26.349	-.57	1519.2	.0298
26.	18.449	36.549	18.445	-.01	26.363	26.349	.41	1519.3	.0403
30.	18.449	36.550	18.444	.07	26.363	26.349	.25	1519.3	.0464
36.	18.450	36.549	18.444	.55	26.363	26.349	.52	1519.4	.0571
50.	18.448	36.551	18.440	.16	26.364	26.351	.10	1519.7	.0805
66.	18.451	36.550	18.440	-.01	26.363	26.351	.64	1519.9	.1075
76.	18.452	36.551	18.439	-.03	26.363	26.351	-.84	1520.1	.1244
100.	18.459	36.551	18.442	.19	26.361	26.350	-.16	1520.5	.1650
126.	18.462	36.550	18.440	-.16	26.360	26.351	-.16	1521.0	.2094
150.	18.458	36.552	18.432	-.17	26.362	26.354	.33	1521.4	.2505
200.	18.462	36.551	18.427	.13	26.361	26.355	.74	1522.2	.3367
250.	18.442	36.555	18.398	.42	26.369	26.365	.61	1523.0	.4242
300.	18.400	36.555	18.348	.92	26.379	26.378	.89	1523.7	.5118
350.	18.339	36.548	18.277	2.99	26.389	26.390	1.12	1524.3	.5998
400.	18.244	36.535	18.174	.82	26.403	26.406	1.51	1524.9	.6878
450.	17.914	36.493	17.836	10.01	26.453	26.458	1.94	1524.7	.7753
500.	17.545	36.442	17.459	.22	26.506	26.512	1.21	1524.4	.8604
550.	17.139	36.372	17.046	23.91	26.550	26.558	2.18	1523.9	.9454
600.	16.646	36.286	16.547	11.49	26.603	26.611	2.14	1523.2	1.0279
650.	15.797	36.140	15.693	20.31	26.688	26.696	2.36	1521.3	1.1079
700.	14.985	36.004	14.877	32.25	26.766	26.774	2.68	1519.4	1.1838
750.	13.704	35.800	13.594	25.90	26.885	26.891	2.81	1515.9	1.2554
800.	12.497	35.615	12.387	20.59	26.987	26.992	2.78	1512.5	1.3220
900.	9.888	35.283	9.781	15.30	27.211	27.211	2.54	1504.6	1.4390
1000.	8.127	35.140	8.020	6.89	27.384	27.381	2.71	1499.6	1.5361
1100.	6.608	35.088	6.502	19.93	27.562	27.556	2.42	1495.4	1.6150
1200.	5.526	35.044	5.419	11.78	27.668	27.660	1.79	1492.7	1.6787
1300.	5.118	35.040	5.004	.16	27.714	27.707	1.37	1492.7	1.7352
1400.	4.752	35.021	4.633	5.50	27.742	27.734	.94	1492.9	1.7882
1500.	4.502	35.004	4.376	1.97	27.757	27.750	.84	1493.5	1.8397
1600.	4.284	34.990	4.152	1.99	27.769	27.762	.72	1494.2	1.8898
1800.	4.058	34.983	3.909	10.19	27.788	27.782	.66	1496.6	1.9892
2000.	3.969	34.993	3.802	1.22	27.805	27.801	.64	1499.6	2.0875
2200.	3.796	34.988	3.612	.83	27.819	27.817	.62	1502.3	2.1850
2400.	3.609	34.984	3.408	1.78	27.835	27.834	.69	1504.8	2.2812
2500.	3.519	34.979	3.310	2.61	27.840	27.839	.57	1506.1	2.3287
2600.	3.439	34.976	3.221	1.42	27.846	27.845	.64	1507.5	2.3762
2800.	3.268	34.966	3.032	.72	27.854	27.855	.61	1510.1	2.4703
3000.	3.110	34.955	2.857	1.49	27.860	27.862	.60	1512.9	2.5636
3200.	2.938	34.945	2.668	.57	27.869	27.872	.57	1515.5	2.6560
3400.	2.803	34.937	2.514	.64	27.874	27.878	.60	1518.4	2.7473
3600.	2.669	34.928	2.362	.71	27.879	27.884	.58	1521.2	2.8380
3800.	2.550	34.922	2.223	.90	27.885	27.891	.53	1524.1	2.9278
4000.	2.456	34.914	2.109	.73	27.886	27.894	.47	1527.2	3.0168
4200.	2.392	34.908	2.024	.12	27.887	27.896	.38	1530.3	3.1059
4400.	2.354	34.905	1.963	.02	27.888	27.898	.32	1533.6	3.1959
4600.	2.334	34.900	1.920	.28	27.886	27.898	.30	1537.0	3.2874
4800.	2.325	34.897	1.887	.07	27.884	27.898	.25	1540.4	3.3807
5000.	2.322	34.894	1.858	.08	27.882	27.898	.25	1543.9	3.4758

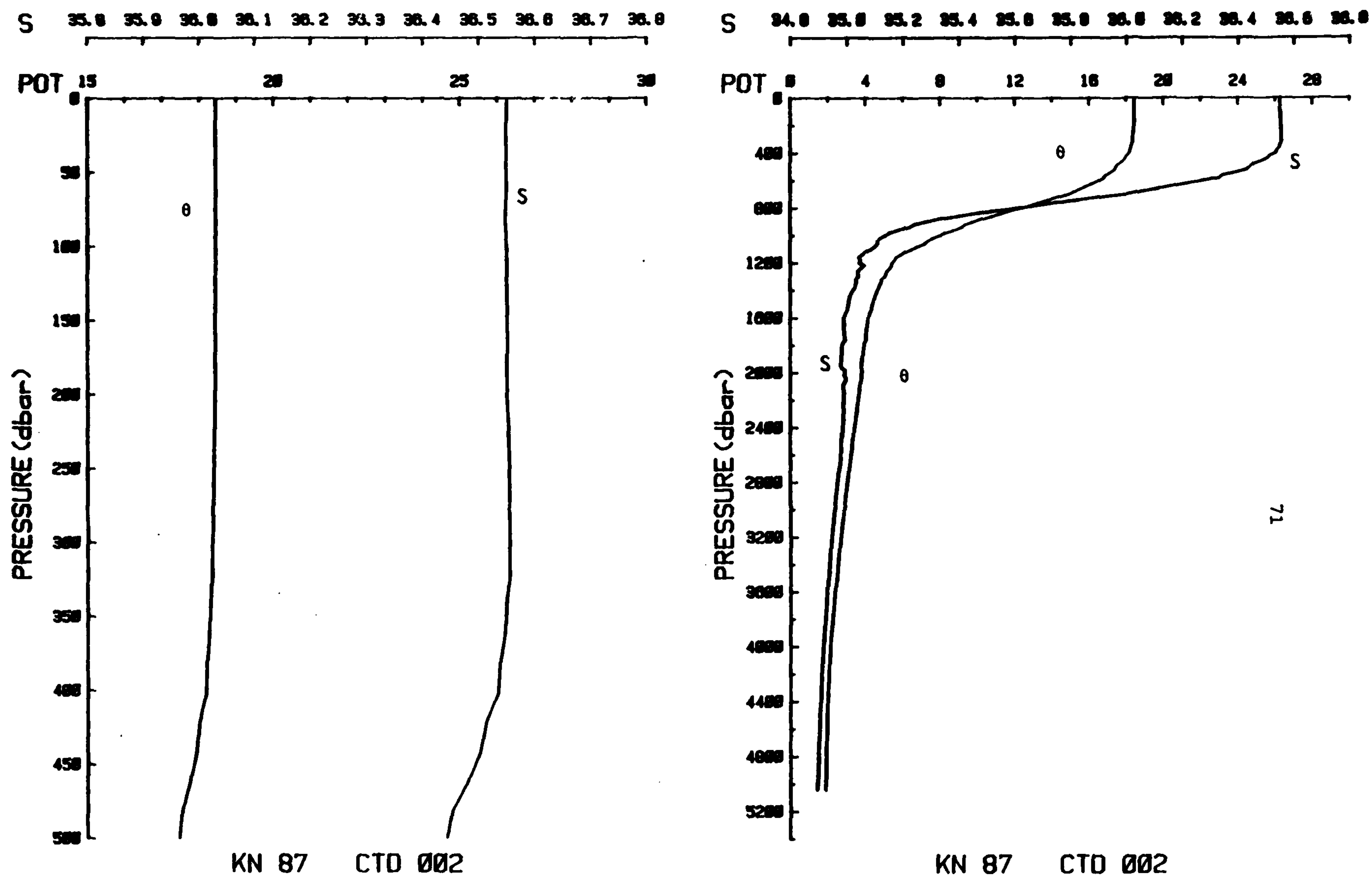


Figure 39: Profiles of potential temperature and salinity from KNORR 87, CTD number 2, 27 Feb. 1981.

KN 87 CTD 007 1981 059 1929Z 32 59.77N 70 00.27W

PRESS dbar	TEMP °C	SALIN psu	POTEMP °C	POTGRD m°C/db	SIGMA-t kg/m**3	POTDEN kg/m**3	BR-V cph	SSPEED m/s	DYNHGT dyn m
2.	18.736	36.575	18.736	0.00	26.310	26.295	0.00	1519.7	0.0000
6.	18.734	36.574	18.733	.30	26.309	26.294	-.38	1519.8	.0068
10.	18.733	36.573	18.732	.56	26.309	26.294	-.85	1519.8	.0134
16.	18.745	36.574	18.742	.01	26.306	26.292	-.80	1520.0	.0241
20.	18.743	36.573	18.740	1.34	26.306	26.292	.47	1520.0	.0310
26.	18.747	36.574	18.743	-1.37	26.306	26.292	.51	1520.1	.0414
30.	18.742	36.573	18.737	2.33	26.307	26.293	-.10	1520.2	.0479
36.	18.731	36.573	18.725	3.83	26.309	26.296	1.50	1520.3	.0587
50.	18.715	36.571	18.706	-.00	26.312	26.299	.50	1520.5	.0828
66.	18.702	36.570	18.691	.83	26.314	26.302	.69	1520.7	.1108
76.	18.700	36.570	18.686	-.05	26.315	26.303	.19	1520.8	.1278
100.	18.673	36.570	18.656	.88	26.322	26.311	1.48	1521.2	.1698
126.	18.571	36.563	18.549	3.10	26.342	26.333	1.79	1521.3	.2148
150.	18.537	36.561	18.511	1.01	26.349	26.341	.62	1521.6	.2565
200.	18.516	36.558	18.480	-.79	26.352	26.346	.55	1522.4	.3434
250.	18.445	36.552	18.401	1.87	26.366	26.362	.89	1523.0	.4308
300.	18.450	36.555	18.397	.26	26.367	26.366	.70	1523.8	.5183
350.	18.344	36.549	18.283	.74	26.389	26.390	1.44	1524.4	.6068
400.	18.190	36.532	18.120	4.10	26.414	26.417	1.49	1524.7	.6941
450.	17.894	36.489	17.816	4.89	26.455	26.460	1.59	1524.6	.7815
500.	17.636	36.452	17.550	5.22	26.491	26.497	1.34	1524.7	.8676
550.	17.320	36.403	17.227	4.42	26.530	26.538	1.58	1524.5	.9529
600.	16.675	36.291	16.576	4.92	26.599	26.607	2.42	1523.3	1.0363
650.	15.834	36.140	15.730	29.34	26.679	26.688	2.27	1521.4	1.1168
700.	14.968	35.998	14.860	9.72	26.765	26.773	2.75	1519.3	1.1934
750.	13.701	35.795	13.592	6.69	26.882	26.888	2.48	1515.8	1.2643
800.	12.630	35.635	12.519	10.16	26.976	26.982	2.47	1512.9	1.3311
900.	10.326	35.333	10.216	42.52	27.174	27.175	3.29	1506.3	1.4516
1000.	8.440	35.173	8.331	19.23	27.362	27.360	2.60	1500.8	1.5506
1100.	6.775	35.079	6.668	5.62	27.533	27.527	2.66	1496.0	1.6322
1200.	5.883	35.082	5.773	12.98	27.653	27.646	1.83	1494.2	1.6987
1300.	5.373	35.063	5.257	2.76	27.702	27.695	1.27	1493.8	1.7572
1400.	4.963	35.045	4.842	-3.00	27.737	27.730	1.01	1493.7	1.8117
1500.	4.704	35.030	4.576	3.01	27.755	27.748	.95	1494.3	1.8640
1600.	4.615	35.044	4.478	2.04	27.776	27.770	.82	1495.7	1.9150
1800.	4.230	35.021	4.078	.90	27.800	27.795	.68	1497.4	2.0140
2000.	4.013	35.015	3.845	.33	27.818	27.814	.67	1499.8	2.1107
2200.	3.723	34.994	3.540	.72	27.831	27.829	.68	1502.0	2.2058
2400.	3.505	34.981	3.306	.46	27.843	27.841	.63	1504.4	2.2993
2500.	3.410	34.975	3.203	.19	27.847	27.846	.52	1505.7	2.3455
2600.	3.296	34.966	3.080	.77	27.852	27.851	.61	1506.9	2.3917
2800.	3.132	34.954	2.900	-.09	27.858	27.858	.58	1509.5	2.4831
3000.	2.965	34.943	2.715	1.30	27.864	27.866	.60	1512.2	2.5743
3200.	2.784	34.932	2.517	.60	27.872	27.875	.60	1514.9	2.6637
3400.	2.632	34.923	2.347	.22	27.878	27.882	.56	1517.6	2.7518
3600.	2.511	34.916	2.207	.94	27.883	27.887	.50	1520.5	2.8388
3800.	2.428	34.909	2.104	.23	27.885	27.891	.38	1523.6	2.9257
4000.	2.384	34.905	2.039	.12	27.886	27.893	.36	1526.8	3.0129
4200.	2.346	34.901	1.979	.59	27.886	27.894	.32	1530.1	3.1014
4400.	2.325	34.899	1.935	.30	27.885	27.896	.30	1533.5	3.1913
4600.	2.314	34.893	1.900	-.07	27.882	27.894	.25	1536.9	3.2828
4800.	2.309	34.891	1.871	.12	27.880	27.894	.25	1540.3	3.3763
5000.	2.306	34.888	1.843	.09	27.878	27.894	.23	1543.8	3.4717

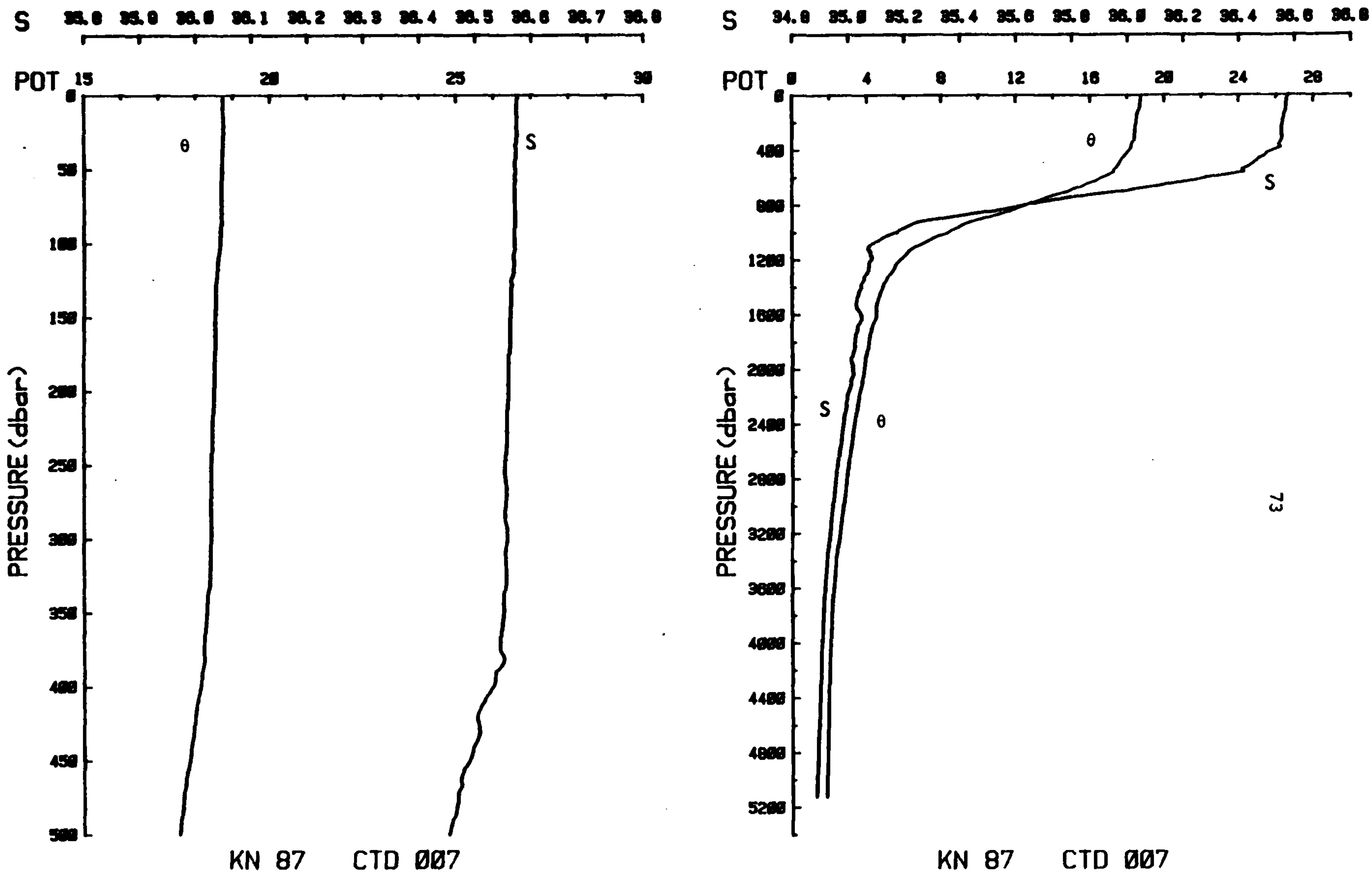


Figure 40: Profiles of potential temperature and salinity from KNORR 87, CTD number 7, 28 Feb. 1981.

KN 87 CTD 008 1981 060 0246Z 33 00.17N 68 59.98W

PRESS dbar	TEMP °C	SALIN psu	POTEMP °C	POTGRD m°C/db	SIGMA-t kg/m**3	POTDEN kg/m**3	BR-V cph	SSPEED m/s	DYNHGT dyn m
2.	18.301	36.563	18.301	0.00	26.410	26.395	0.00	1518.5	0.0000
6.	18.306	36.561	18.305	-.57	26.408	26.393	-1.15	1518.5	.0068
10.	18.311	36.561	18.310	.11	26.407	26.392	-.19	1518.6	.0128
16.	18.306	36.561	18.304	-.02	26.408	26.393	.61	1518.7	.0228
20.	18.308	36.561	18.304	-.08	26.408	26.393	-.79	1518.8	.0295
26.	18.316	36.561	18.311	-.87	26.405	26.391	-.65	1518.9	.0389
30.	18.317	36.561	18.312	-.22	26.405	26.391	-.68	1519.0	.0451
36.	18.325	36.561	18.319	-1.15	26.403	26.389	-.88	1519.1	.0556
50.	18.328	36.560	18.319	-.39	26.402	26.389	-.59	1519.3	.0778
66.	18.331	36.560	18.320	-.15	26.401	26.389	-.17	1519.6	.1049
76.	18.332	36.560	18.319	-.07	26.400	26.389	-.37	1519.8	.1213
100.	18.335	36.560	18.318	.10	26.400	26.389	-.28	1520.2	.1615
126.	18.339	36.560	18.317	.32	26.399	26.389	-.12	1520.6	.2046
150.	18.344	36.560	18.318	-.28	26.397	26.389	.12	1521.0	.2448
200.	18.354	36.559	18.319	.36	26.395	26.388	-.19	1521.9	.3300
250.	18.359	36.560	18.315	.08	26.393	26.389	-.20	1522.7	.4154
300.	18.328	36.553	18.276	3.80	26.396	26.394	1.29	1523.5	.5021
350.	18.100	36.520	18.039	4.70	26.428	26.429	1.37	1523.6	.5893
400.	17.903	36.494	17.834	.12	26.457	26.459	1.35	1523.8	.6745
450.	17.719	36.469	17.642	8.64	26.483	26.487	1.66	1524.1	.7603
500.	17.483	36.434	17.397	7.02	26.515	26.521	1.54	1524.2	.8450
550.	17.139	36.375	17.046	7.30	26.553	26.560	1.58	1523.9	.9286
600.	16.722	36.295	16.623	10.06	26.591	26.599	2.47	1523.4	1.0119
650.	15.920	36.157	15.816	21.51	26.673	26.682	2.81	1521.7	1.0921
700.	14.834	35.976	14.726	27.49	26.778	26.786	2.91	1518.9	1.1686
750.	13.968	35.839	13.857	19.28	26.859	26.867	2.31	1516.8	1.2406
800.	12.715	35.646	12.604	12.92	26.969	26.974	2.80	1513.2	1.3079
900.	10.135	35.300	10.026	45.00	27.182	27.182	3.18	1505.5	1.4279
1000.	8.118	35.136	8.011	19.34	27.383	27.379	2.97	1499.6	1.5267
1100.	6.591	35.080	6.485	5.48	27.559	27.553	2.03	1495.3	1.6044
1200.	5.768	35.064	5.659	5.10	27.654	27.647	1.80	1493.7	1.6694
1300.	5.258	35.057	5.143	2.18	27.711	27.703	1.27	1493.3	1.7268
1400.	4.869	35.033	4.749	2.71	27.738	27.730	.95	1493.3	1.7806
1500.	4.660	35.024	4.532	7.19	27.755	27.748	.88	1494.1	1.8328
1600.	4.408	35.003	4.274	.12	27.766	27.760	.74	1494.8	1.8839
1800.	4.153	34.993	4.002	.74	27.786	27.780	.70	1497.0	1.9843
2000.	3.964	34.990	3.797	-.25	27.803	27.799	.67	1499.6	2.0832
2200.	3.792	34.989	3.608	.67	27.820	27.818	.71	1502.2	2.1807
2400.	3.575	34.979	3.374	.86	27.835	27.833	.67	1504.7	2.2764
2500.	3.486	34.976	3.277	3.24	27.841	27.840	.72	1506.0	2.3238
2600.	3.372	34.967	3.155	.53	27.845	27.845	.54	1507.2	2.3710
2800.	3.172	34.956	2.939	1.61	27.856	27.856	.66	1509.7	2.4640
3000.	2.992	34.946	2.741	.73	27.864	27.866	.58	1512.3	2.5555
3200.	2.837	34.936	2.569	1.90	27.871	27.873	.64	1515.1	2.6460
3400.	2.667	34.926	2.381	.60	27.877	27.881	.56	1517.8	2.7348
3600.	2.530	34.917	2.226	1.35	27.883	27.887	.56	1520.6	2.8226
3800.	2.422	34.910	2.098	.19	27.886	27.892	.47	1523.6	2.9095
4000.	2.366	34.904	2.021	.25	27.887	27.894	.40	1526.8	2.9964
4200.	2.328	34.900	1.961	.51	27.886	27.895	.30	1530.0	3.0845
4400.	2.308	34.897	1.918	.52	27.886	27.896	.31	1533.4	3.1739
4600.	2.294	34.893	1.881	.12	27.883	27.895	.23	1536.8	3.2648
4800.	2.294	34.889	1.856	.09	27.881	27.895	.15	1540.3	3.3579
5000.	2.303	34.887	1.840	.13	27.878	27.894	.19	1543.8	3.4532
5200.	2.293	34.883	1.805	.72	27.875	27.893	0.00	1547.2	3.5506

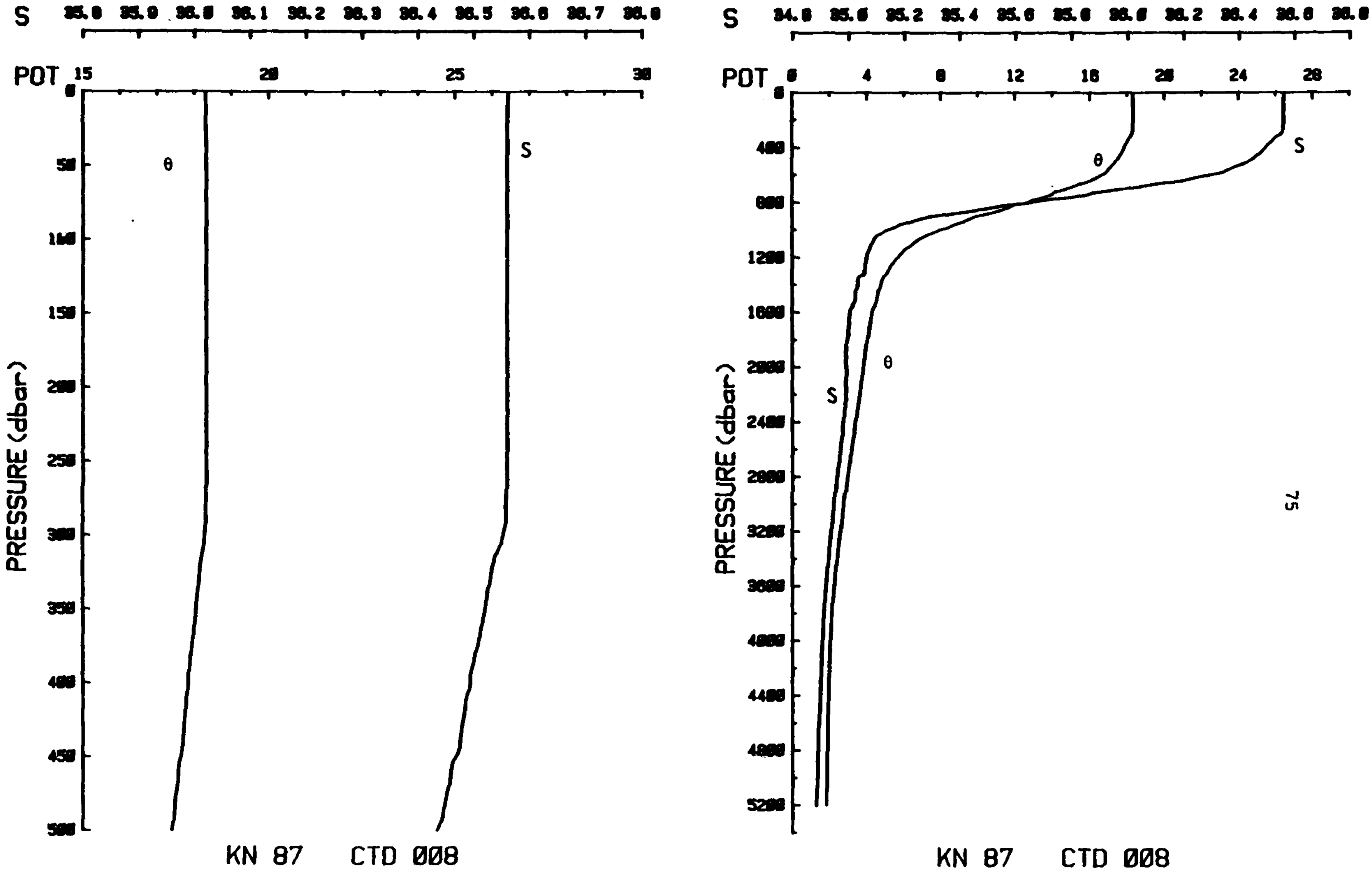


Figure 41: Profiles of potential temperature and salinity from KNORR 87, CTD number 8, 28 Feb. 1981.

KN 87 CTD 010 1981 061 0541Z 35 00.25N 69 59.97W

PRESS dbar	TEMP °C	SALIN psu	POTEMP °C	POTGRD m°C/db	SIGMA-t kg/m**3	POTDEN kg/m**3	BR-V cph	SSPEED m/s	DYNHGT dyn m
2.	19.060	36.562	19.060	0.00	26.217	26.202	0.00	1520.6	0.0000
6.	19.059	36.563	19.059	.24	26.217	26.202	.37	1520.7	.0074
10.	19.062	36.563	19.060	-.79	26.217	26.202	.28	1520.8	.0143
16.	19.060	36.563	19.058	-.13	26.217	26.203	.57	1520.9	.0255
20.	19.060	36.563	19.057	.05	26.217	26.203	.54	1520.9	.0326
26.	19.058	36.563	19.054	.09	26.218	26.204	.36	1521.0	.0433
30.	19.058	36.563	19.053	.07	26.218	26.204	.43	1521.1	.0507
36.	19.054	36.563	19.048	.03	26.219	26.205	1.11	1521.2	.0617
50.	19.001	36.560	18.992	7.86	26.230	26.217	2.06	1521.3	.0872
66.	18.714	36.555	18.703	22.88	26.300	26.288	3.68	1520.7	.1158
76.	18.670	36.554	18.657	.28	26.310	26.299	.36	1520.7	.1333
100.	18.625	36.547	18.607	5.38	26.316	26.306	2.10	1521.0	.1752
126.	18.554	36.544	18.532	3.77	26.332	26.323	1.94	1521.2	.2202
150.	18.503	36.546	18.477	1.22	26.346	26.338	1.15	1521.5	.2621
200.	18.475	36.547	18.440	.27	26.354	26.348	.54	1522.2	.3488
250.	18.480	36.553	18.436	-.67	26.358	26.354	.76	1523.1	.4366
300.	18.482	36.556	18.430	.18	26.360	26.358	.49	1523.9	.5248
350.	18.465	36.555	18.403	1.18	26.363	26.364	.96	1524.7	.6139
400.	18.244	36.536	18.174	1.53	26.405	26.407	1.71	1524.9	.7027
450.	18.018	36.511	17.940	4.65	26.442	26.446	1.70	1525.0	.7902
500.	17.738	36.471	17.652	3.00	26.481	26.487	1.33	1525.0	.8768
550.	17.454	36.428	17.360	7.57	26.517	26.525	1.48	1524.9	.9627
600.	16.869	36.327	16.769	12.10	26.581	26.589	2.33	1523.9	1.0464
650.	16.090	36.189	15.985	8.10	26.658	26.667	2.34	1522.2	1.1282
700.	15.153	36.031	15.044	6.43	26.750	26.759	2.23	1519.9	1.2053
750.	14.136	35.868	14.024	6.53	26.846	26.854	2.47	1517.3	1.2789
800.	13.097	35.705	12.983	13.96	26.937	26.944	1.85	1514.6	1.3477
900.	10.557	35.356	10.445	9.55	27.151	27.153	3.01	1507.1	1.4715
1000.	8.357	35.143	8.248	24.36	27.352	27.349	2.90	1500.5	1.5723
1100.	6.398	35.066	6.293	20.80	27.574	27.567	2.23	1494.5	1.6524
1200.	5.572	35.044	5.464	6.17	27.663	27.655	1.55	1492.9	1.7160
1300.	5.113	35.041	4.999	3.11	27.715	27.708	.97	1492.7	1.7726
1400.	4.869	35.035	4.749	8.88	27.739	27.732	1.21	1493.4	1.8262
1500.	4.635	35.024	4.507	2.19	27.757	27.750	.87	1494.0	1.8780
1600.	4.457	35.016	4.322	.19	27.771	27.764	.78	1495.0	1.9289
1800.	4.138	34.994	3.988	.18	27.788	27.783	.66	1497.0	2.0288
2000.	3.954	34.990	3.787	3.02	27.804	27.800	.78	1499.6	2.1272
2200.	3.787	34.989	3.603	-1.23	27.821	27.818	.70	1502.2	2.2245
2400.	3.597	34.982	3.396	.83	27.835	27.834	.66	1504.8	2.3204
2500.	3.520	34.980	3.310	.23	27.841	27.840	.44	1506.1	2.3679
2600.	3.455	34.977	3.237	.73	27.845	27.844	.65	1507.6	2.4154
2800.	3.243	34.964	3.008	1.11	27.855	27.856	.61	1510.0	2.5095
3000.	3.074	34.955	2.822	.09	27.864	27.866	.60	1512.7	2.6021
3200.	2.910	34.946	2.640	1.10	27.872	27.875	.70	1515.4	2.6935
3400.	2.726	34.936	2.439	.36	27.881	27.884	.57	1518.0	2.7832
3600.	2.566	34.926	2.261	1.17	27.886	27.891	.61	1520.8	2.8710
3800.	2.431	34.917	2.107	.87	27.891	27.897	.59	1523.6	2.9576
4000.	2.363	34.911	2.019	-.01	27.892	27.899	.37	1526.8	3.0437
4200.	2.321	34.907	1.955	.45	27.892	27.901	.36	1530.0	3.1307
4400.	2.306	34.903	1.917	.12	27.890	27.901	.20	1533.4	3.2190
4600.	2.298	34.900	1.884	.09	27.889	27.901	-.10	1536.8	3.3092
4800.	2.299	34.896	1.861	.04	27.886	27.900	.16	1540.3	3.4013

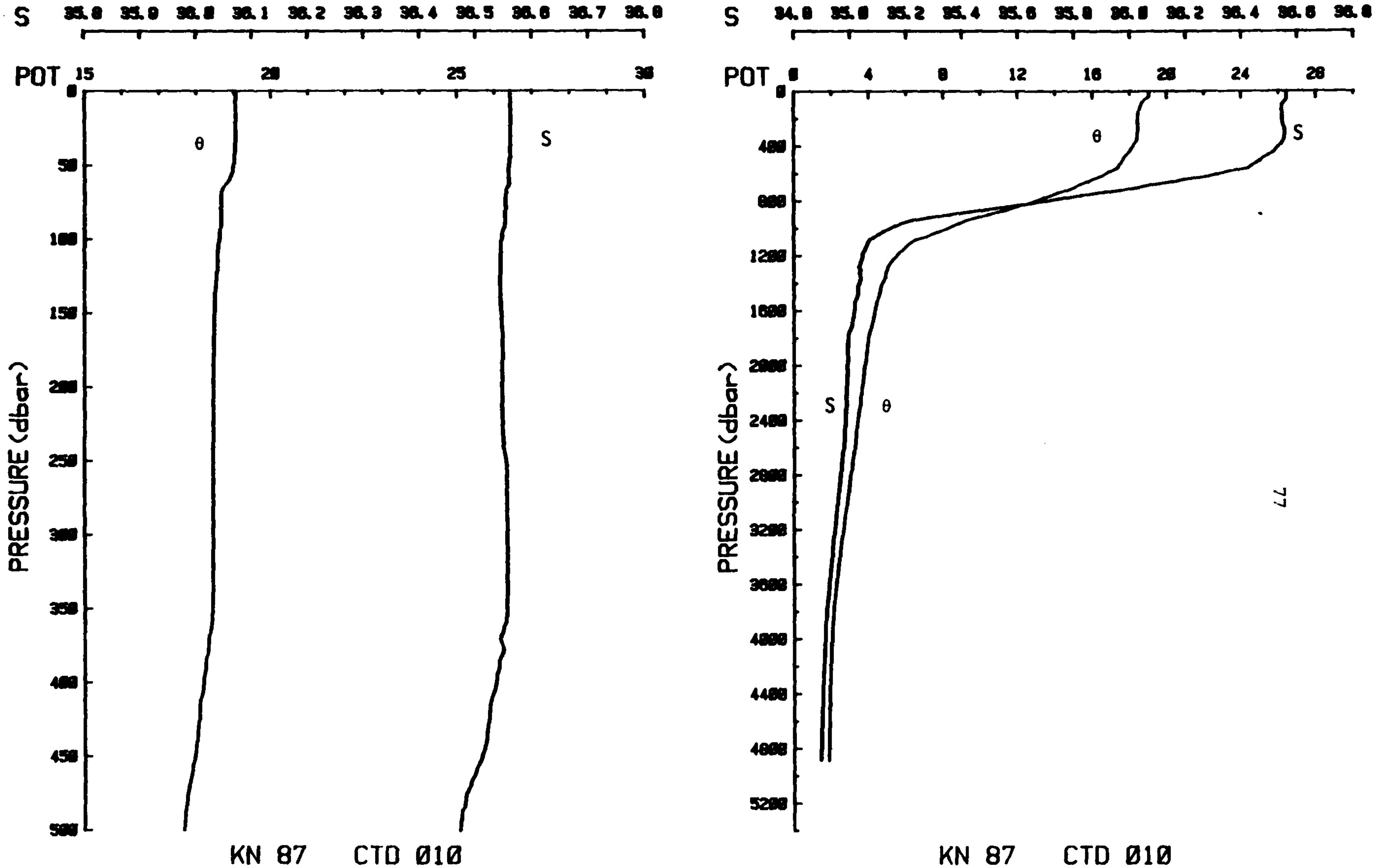


Figure 42: Profiles of potential temperature and salinity from KNORR 87, CTD number 10, 2 Mar. 1981.

OCEANUS 96

MAY 1981

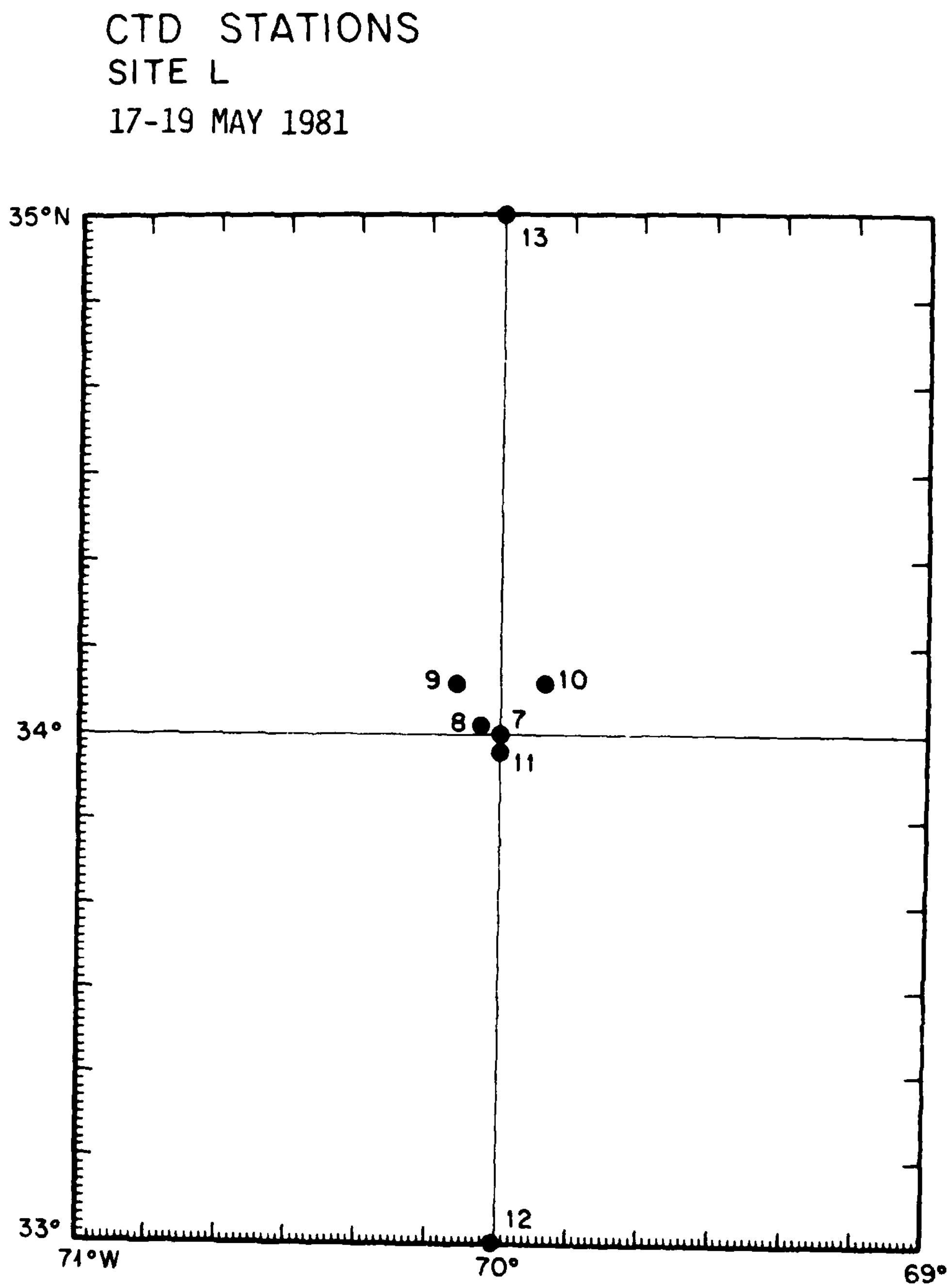


Figure 43: Chart showing the locations of CTD stations made during OCEANUS 96, May 1981.

OC 96   CTD 007   1981 137 0416Z   33 59.24N 69 59.25W

PRESS dbar	TEMP °C	SALIN psu	POTEMP °C	POTGRD m°C/db	SIGMA-t kg/m**3	POTDEN kg/m**3	BR-V cph	SSPEED m/s	DYNHGT dyn m
2.	20.711	36.517	20.711	0.00	25.745	25.729	0.00	1525.1	0.0000
6.	20.713	36.517	20.712	.52	25.745	25.730	.25	1525.2	.0090
10.	20.714	36.517	20.712	.80	25.745	25.729	4.07	1525.3	.0185
16.	20.203	36.509	20.200	138.67	25.876	25.861	9.30	1524.0	.0313
20.	19.925	36.514	19.921	46.84	25.954	25.940	7.93	1523.3	.0401
26.	19.582	36.521	19.578	8.25	26.050	26.036	6.80	1522.4	.0518
30.	19.304	36.518	19.299	102.48	26.120	26.106	7.20	1521.7	.0597
36.	18.952	36.535	18.946	74.06	26.224	26.210	6.75	1520.9	.0710
50.	18.620	36.555	18.612	22.10	26.324	26.311	4.25	1520.2	.0958
66.	18.399	36.556	18.388	7.62	26.380	26.368	2.32	1519.8	.1224
76.	18.304	36.544	18.291	22.92	26.395	26.383	2.75	1519.7	.1391
100.	18.223	36.551	18.205	-5.05	26.421	26.410	1.33	1519.8	.1786
126.	18.144	36.548	18.122	.94	26.438	26.429	1.38	1520.1	.2218
150.	18.047	36.530	18.021	2.40	26.449	26.441	1.35	1520.2	.2614
200.	17.945	36.524	17.910	2.18	26.470	26.464	1.07	1520.7	.3427
250.	17.888	36.520	17.845	.56	26.480	26.476	.81	1521.3	.4242
300.	17.800	36.478	17.749	.53	26.470	26.468	.32	1521.9	.5063
350.	17.707	36.495	17.647	5.04	26.506	26.506	.80	1522.4	.5891
400.	17.484	36.451	17.416	2.29	26.527	26.529	1.22	1522.6	.6714
450.	17.188	36.393	17.112	-.35	26.555	26.558	1.78	1522.6	.7534
500.	16.662	36.284	16.579	7.17	26.597	26.601	1.91	1521.6	.8341
550.	15.778	36.129	15.690	8.69	26.684	26.689	2.36	1519.5	.9129
600.	14.759	35.962	14.668	12.05	26.784	26.788	2.28	1517.0	.9879
650.	13.877	35.820	13.782	33.18	26.864	26.868	2.72	1514.8	1.0585
700.	12.746	35.646	12.648	27.73	26.962	26.965	2.53	1511.7	1.1247
750.	11.590	35.489	11.492	28.75	27.065	27.066	2.59	1508.4	1.1868
800.	10.391	35.336	10.293	40.14	27.165	27.164	2.52	1504.8	1.2435
900.	8.225	35.137	8.128	13.64	27.367	27.362	2.44	1498.3	1.3425
1000.	6.638	35.065	6.542	16.45	27.541	27.533	2.57	1493.8	1.4223
1100.	5.706	35.049	5.607	16.02	27.650	27.642	2.15	1491.8	1.4875
1200.	5.102	35.014	4.998	.24	27.696	27.687	1.15	1490.9	1.5443
1300.	4.766	35.005	4.656	1.89	27.728	27.719	.95	1491.2	1.5980
1400.	4.559	35.002	4.442	2.86	27.749	27.741	.93	1492.0	1.6494
1500.	4.404	35.000	4.279	5.22	27.764	27.757	.75	1493.1	1.6998
1600.	4.264	34.993	4.132	3.50	27.774	27.767	.74	1494.1	1.7494
1800.	4.021	34.985	3.873	1.58	27.793	27.787	.73	1496.5	1.8475
2000.	3.877	34.983	3.711	-.07	27.807	27.802	.66	1499.2	1.9443
2200.	3.714	34.981	3.531	4.71	27.822	27.819	.72	1501.9	2.0408
2400.	3.547	34.976	3.347	.81	27.835	27.833	.65	1504.6	2.1358
2500.	3.458	34.972	3.250	.63	27.841	27.840	.64	1505.9	2.1830
2600.	3.350	34.966	3.133	.39	27.846	27.845	.58	1507.1	2.2299
2800.	3.183	34.956	2.949	.84	27.854	27.855	.57	1509.8	2.3227
3000.	3.008	34.944	2.757	.26	27.861	27.863	.57	1512.4	2.4149
3200.	2.867	34.935	2.598	1.31	27.867	27.870	.56	1515.2	2.5060
3400.	2.724	34.928	2.437	.38	27.874	27.878	.58	1518.0	2.5963
3600.	2.606	34.921	2.300	.96	27.879	27.884	.49	1520.9	2.6858
3800.	2.494	34.913	2.168	1.20	27.882	27.888	.46	1523.9	2.7748
4000.	2.429	34.909	2.082	1.31	27.885	27.892	.46	1527.0	2.8636
4200.	2.376	34.903	2.008	.83	27.885	27.893	.34	1530.3	2.9531
4400.	2.343	34.898	1.952	.84	27.887	27.894	.36	1533.6	3.0436
4600.	2.328	34.894	1.914	.30	27.882	27.894	.21	1537.0	3.1357
4800.	2.323	34.892	1.885	.13	27.880	27.894	.24	1540.4	3.2296
5000.	2.320	34.887	1.857	.36	27.878	27.894	.22	1543.9	3.3252

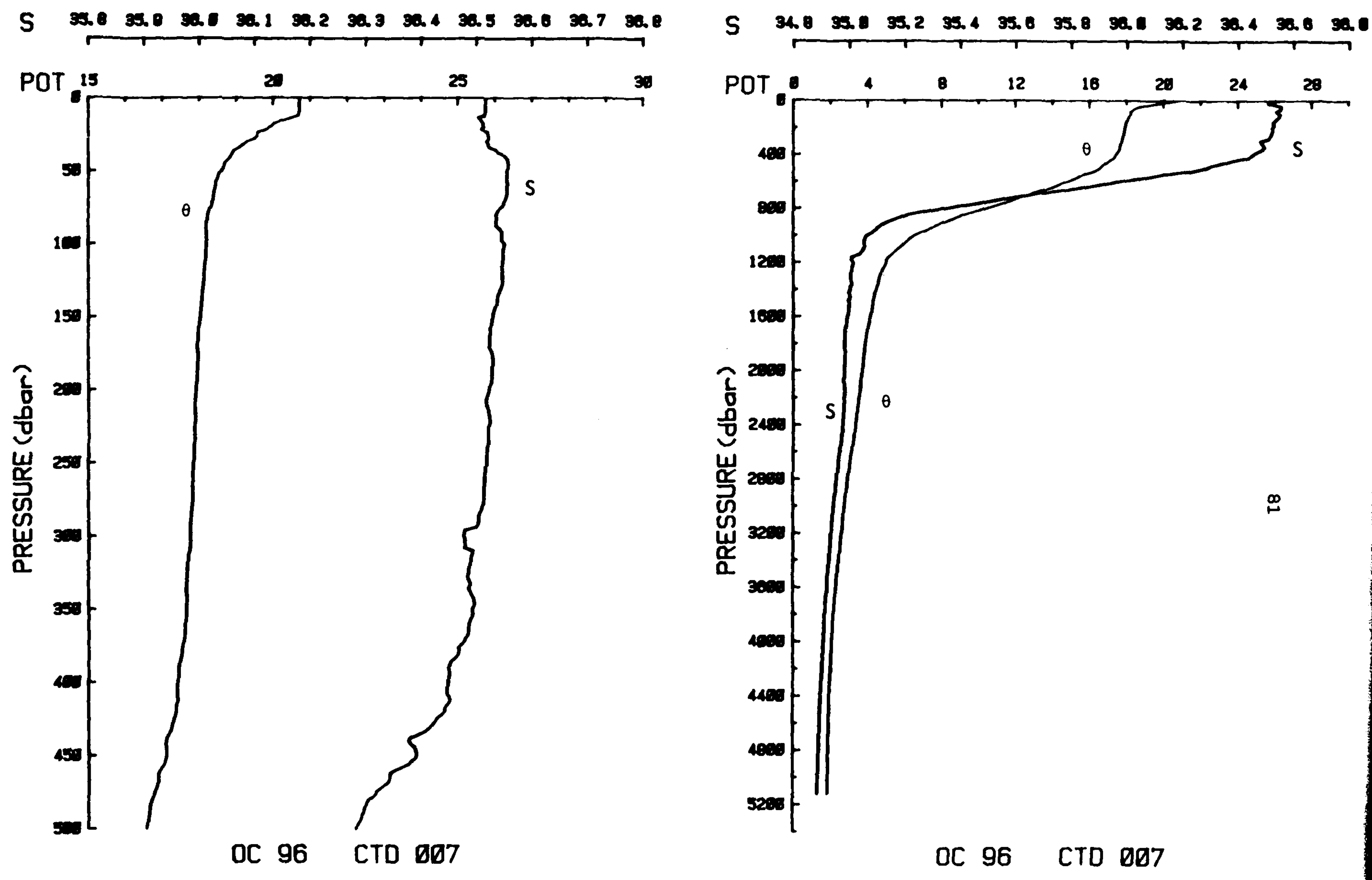
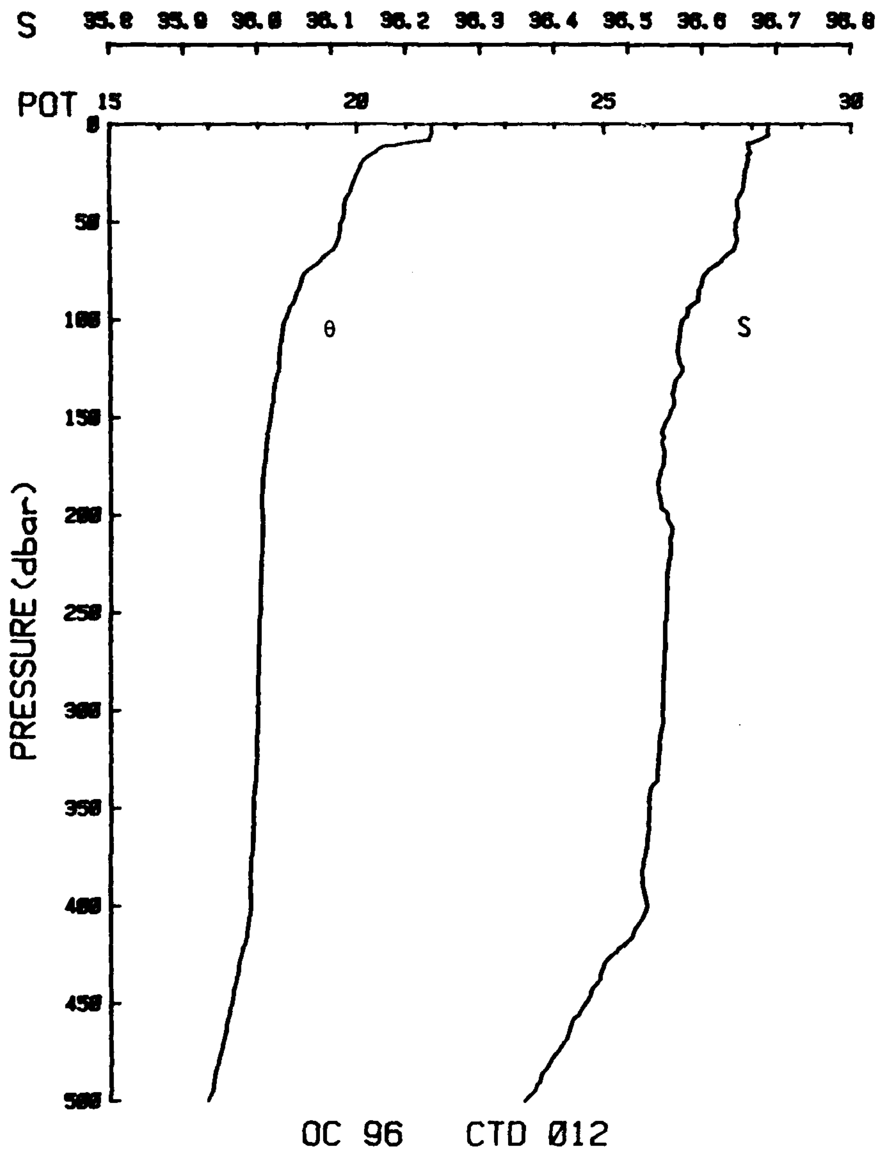


Figure 44: Profiles of potential temperature and salinity from OCEANUS 96, CTD number 7, 17 May 1981.

OC 96 CTD 012 1981 139 1005Z 33 00.13N 69 59.81W

PRESS dbar	TEMP °C	SALIN psu	POTEMP °C	POTGRD m°C/db	SIGMA-t kg/m**3	POTDEN kg/m**3	BR-V cph	SSPEED m/s	DYNHGT dyn m
2.	21.513	36.688	21.513	0.00	25.655	25.639	0.00	1527.5	0.0000
6.	21.509	36.689	21.508	1.68	25.657	25.641	7.06	1527.5	.0085
10.	20.895	36.661	20.894	285.49	25.804	25.789	11.21	1525.9	.0182
16.	20.283	36.661	20.281	64.96	25.970	25.956	6.62	1524.4	.0305
20.	20.102	36.660	20.099	25.43	26.018	26.004	4.72	1523.9	.0392
26.	20.004	36.658	20.000	19.11	26.042	26.028	3.72	1523.8	.0506
30.	19.941	36.656	19.935	15.43	26.058	26.044	3.46	1523.7	.0584
36.	19.852	36.651	19.846	14.60	26.077	26.064	3.44	1523.5	.0702
50.	19.694	36.644	19.685	19.31	26.114	26.102	2.73	1523.3	.0976
66.	19.426	36.634	19.415	54.33	26.177	26.165	5.22	1522.8	.1279
76.	18.947	36.604	18.934	48.56	26.278	26.266	5.01	1521.6	.1465
100.	18.565	36.572	18.548	20.75	26.351	26.341	3.01	1520.9	.1884
126.	18.427	36.573	18.405	3.77	26.386	26.377	2.01	1520.9	.2321
150.	18.276	36.554	18.250	6.06	26.410	26.402	1.75	1520.8	.2723
200.	18.121	36.553	18.087	-4.30	26.448	26.442	1.21	1521.2	.3554
250.	18.071	36.551	18.028	1.42	26.459	26.455	.79	1521.9	.4385
300.	18.035	36.545	17.983	.50	26.463	26.461	.73	1522.6	.5217
350.	17.951	36.527	17.891	.09	26.471	26.471	.84	1523.2	.6059
400.	17.899	36.525	17.830	.22	26.482	26.484	.97	1523.9	.6903
450.	17.523	36.442	17.446	9.32	26.511	26.514	1.74	1523.5	.7744
500.	17.066	36.360	16.982	16.19	26.559	26.564	1.91	1522.9	.8575
550.	16.445	36.251	16.355	21.26	26.622	26.628	2.40	1521.7	.9385
600.	15.377	36.069	15.283	8.76	26.729	26.735	2.57	1519.0	1.0159
650.	14.517	35.927	14.418	3.76	26.809	26.815	2.68	1517.0	1.0893
700.	13.122	35.707	13.023	20.04	26.934	26.937	2.79	1513.0	1.1577
750.	11.883	35.529	11.783	.53	27.041	27.043	1.46	1509.4	1.2202
800.	10.731	35.377	10.631	21.29	27.136	27.136	2.89	1506.1	1.2789
900.	8.158	35.135	8.061	23.08	27.376	27.371	2.67	1498.1	1.3782
1000.	6.843	35.087	6.746	8.57	27.529	27.522	2.20	1494.6	1.4578
1100.	5.985	35.069	5.884	14.74	27.630	27.622	1.88	1492.9	1.5247
1200.	5.258	35.049	5.153	10.38	27.704	27.696	1.62	1491.6	1.5828
1300.	4.825	35.022	4.715	3.43	27.734	27.726	1.14	1491.5	1.6358
1400.	4.572	35.006	4.454	2.52	27.750	27.742	.89	1492.1	1.6870
1500.	4.382	34.994	4.257	2.87	27.762	27.754	.73	1493.0	1.7373
1600.	4.248	34.986	4.116	3.24	27.770	27.763	.71	1494.1	1.7873
1800.	4.065	34.981	3.916	-.01	27.786	27.780	.63	1496.6	1.8863
2000.	3.904	34.981	3.738	.72	27.803	27.798	.69	1499.3	1.9846
2200.	3.770	34.985	3.586	-1.45	27.819	27.817	.58	1502.1	2.0823
2400.	3.609	34.981	3.408	.45	27.832	27.831	.64	1504.8	2.1784
2500.	3.497	34.974	3.288	1.45	27.838	27.837	.68	1506.0	2.2260
2600.	3.406	34.970	3.188	.54	27.844	27.843	.63	1507.3	2.2733
2800.	3.210	34.957	2.975	2.42	27.853	27.853	.63	1509.9	2.3672
3000.	3.059	34.947	2.807	.66	27.859	27.861	0.00	1512.6	2.4599



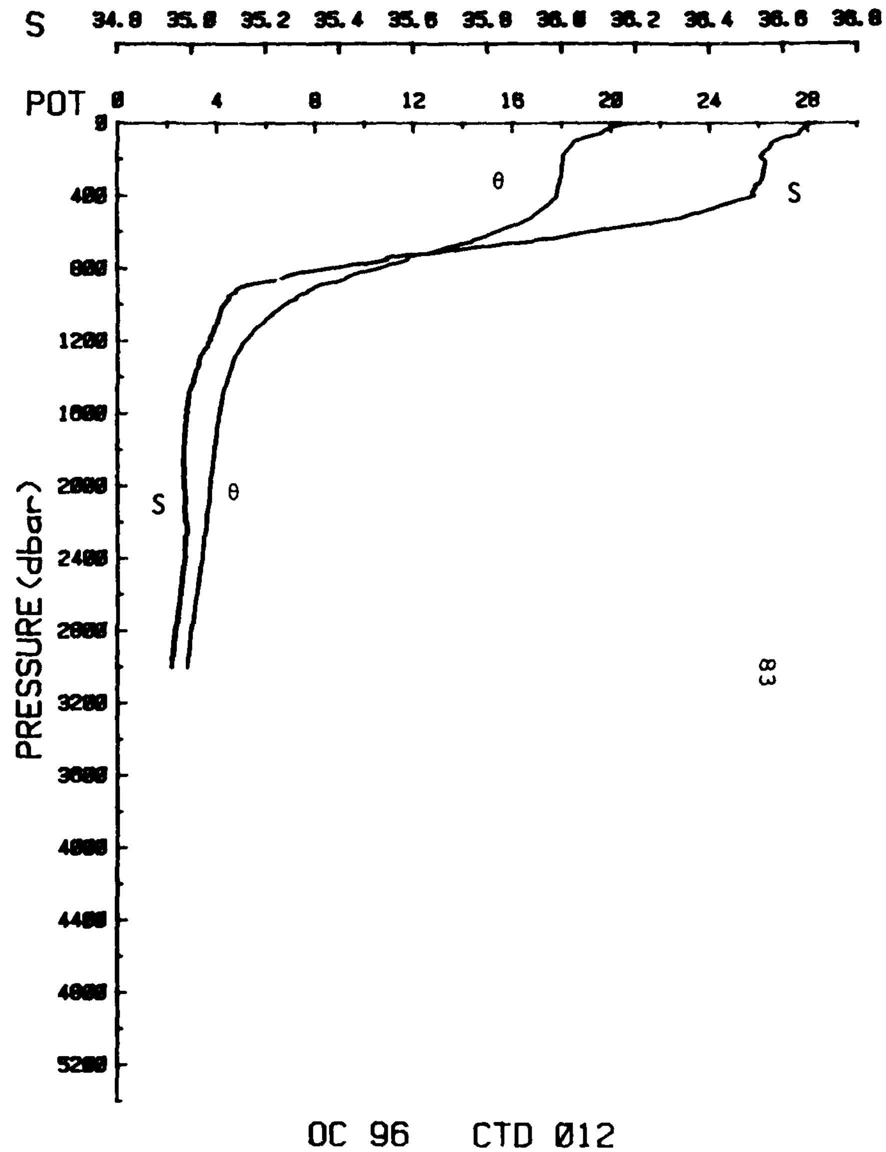


Figure 45: Profiles of potential temperature and salinity from OCEANUS 96, CTD number 12, 19 May 1981.

OC 96 CTD 013 1981 139 2310Z 35 04.00N 69 59.37W

PRESS dbar	TEMP °C	SALIN psu	POTEMP °C	POTGRD m°C/db	SIGMA-t kg/m**3	POTDEN kg/m**3	BR-V cph	SSPEED m/s	DYNHGT dyn m
2.	20.469	36.546	20.469	0.00	25.833	25.817	0.00	1524.5	0.0000
6.	20.470	36.546	20.469	-.67	25.832	25.817	-.69	1524.6	.0092
10.	20.473	36.545	20.472	-.79	25.831	25.816	1.57	1524.7	.0186
16.	20.450	36.544	20.447	-1.73	25.837	25.822	.56	1524.7	.0307
20.	20.450	36.543	20.447	-1.37	25.835	25.821	2.23	1524.8	.0396
26.	20.372	36.539	20.367	11.47	25.854	25.839	5.19	1524.6	.0525
30.	20.086	36.521	20.081	70.54	25.916	25.902	8.38	1523.9	.0609
36.	19.699	36.515	19.692	10.87	26.014	26.001	3.17	1522.9	.0731
50.	19.487	36.524	19.478	31.91	26.077	26.064	4.79	1522.6	.1010
66.	19.102	36.550	19.091	21.38	26.196	26.184	4.78	1521.8	.1318
76.	18.893	36.553	18.879	31.13	26.252	26.241	4.15	1521.4	.1497
100.	18.646	36.555	18.628	6.88	26.317	26.307	2.50	1521.1	.1922
126.	18.445	36.552	18.423	8.72	26.366	26.357	2.17	1520.9	.2373
150.	18.336	36.553	18.310	4.96	26.394	26.386	1.88	1521.0	.2780
200.	18.213	36.543	18.179	1.33	26.418	26.411	1.07	1521.5	.3623
250.	18.153	36.539	18.110	8.48	26.429	26.425	1.05	1522.1	.4461
300.	18.070	36.539	18.018	1.26	26.450	26.448	.92	1522.7	.5304
350.	17.961	36.527	17.900	2.43	26.468	26.468	1.08	1523.2	.6153
400.	17.899	36.519	17.830	-.01	26.477	26.479	.83	1523.9	.6997
450.	17.815	36.506	17.738	1.09	26.488	26.493	.87	1524.4	.7846
500.	17.716	36.488	17.630	.98	26.499	26.505	1.02	1524.9	.8697
550.	17.604	36.468	17.510	3.01	26.511	26.519	1.25	1525.4	.9549
600.	17.374	36.427	17.272	6.32	26.536	26.546	1.73	1525.5	1.0405
650.	16.519	36.252	16.412	29.80	26.606	26.616	2.51	1523.6	1.1241
700.	15.525	36.079	15.415	17.98	26.703	26.713	2.71	1521.2	1.2045
750.	14.588	35.926	14.474	11.71	26.794	26.803	2.35	1518.9	1.2805
800.	13.291	35.722	13.177	19.58	26.911	26.918	3.14	1515.2	1.3515
900.	10.781	35.373	10.667	21.95	27.124	27.127	2.72	1507.9	1.4785
1000.	8.638	35.156	8.527	11.25	27.317	27.316	2.83	1501.6	1.5845
1100.	6.754	35.069	6.646	14.81	27.528	27.522	2.54	1495.9	1.6685
1200.	5.505	35.021	5.398	5.43	27.652	27.644	1.84	1492.6	1.7343
1300.	4.921	34.990	4.809	.51	27.698	27.690	1.36	1491.8	1.7915
1400.	4.714	34.998	4.596	3.15	27.728	27.720	.81	1492.7	1.8454
1500.	4.609	35.002	4.482	2.84	27.743	27.736	.86	1493.9	1.8985
1600.	4.414	34.994	4.280	1.03	27.758	27.752	.76	1494.8	1.9504
1800.	4.130	34.978	3.980	.91	27.776	27.771	.70	1496.9	2.0524
2000.	3.962	34.977	3.796	.62	27.793	27.789	.57	1499.6	2.1529
2200.	3.795	34.974	3.611	1.09	27.808	27.806	.72	1502.2	2.2526
2400.	3.629	34.969	3.428	.28	27.821	27.820	.59	1504.9	2.3511
2500.	3.541	34.967	3.331	.68	27.828	27.827	.64	1506.2	2.4001
2600.	3.423	34.961	3.205	3.32	27.835	27.835	.66	1507.4	2.4486
2800.	3.242	34.952	3.007	.24	27.846	27.846	.60	1510.0	2.5444
3000.	3.058	34.942	2.806	.11	27.855	27.857	.66	1512.6	2.6384
3200.	2.865	34.930	2.596	.87	27.863	27.865	.65	1515.2	2.7311
3400.	2.700	34.922	2.413	.75	27.871	27.875	.61	1517.9	2.8221
3600.	2.576	34.914	2.270	1.05	27.876	27.881	.52	1520.8	2.9114
3800.	2.444	34.906	2.120	1.16	27.881	27.887	.56	1523.7	3.0000
4000.	2.390	34.901	2.045	.65	27.882	27.889	.42	1526.9	3.0882
4200.	2.330	34.894	1.963	.11	27.881	27.890	.35	1530.0	3.1773
4400.	2.306	34.892	1.917	.18	27.881	27.892	.33	1533.4	3.2674
4600.	2.300	34.887	1.886	.15	27.878	27.890	-.04	1536.8	3.3594

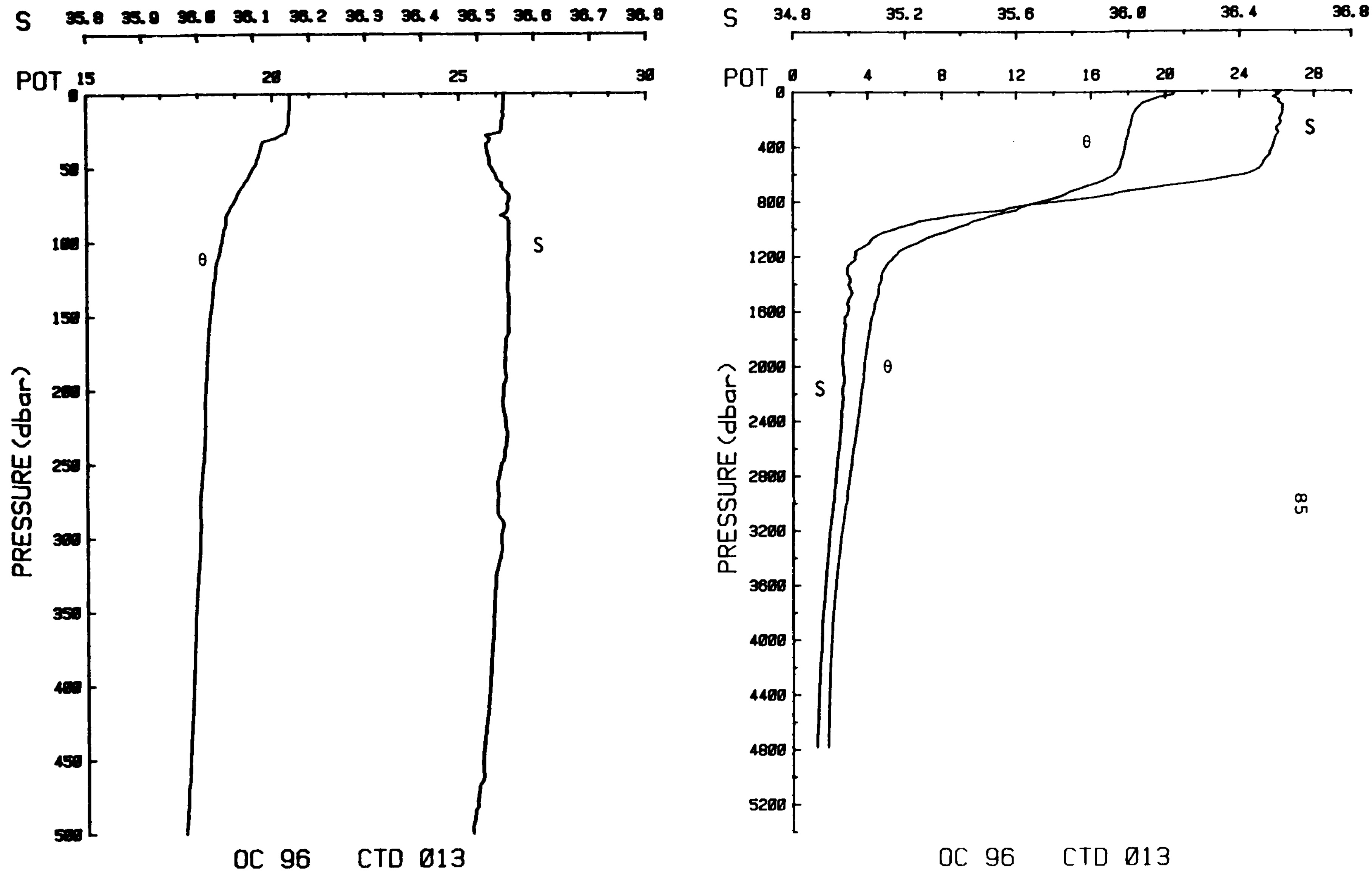


Figure 46: Profiles of potential temperature and salinity from OCEANUS 96, CTD number 13, 19 May 1981.

OCEANUS 103

SEPTEMBER 1981

CTD STATIONS

SITE L

13-14 SEPTEMBER 1981

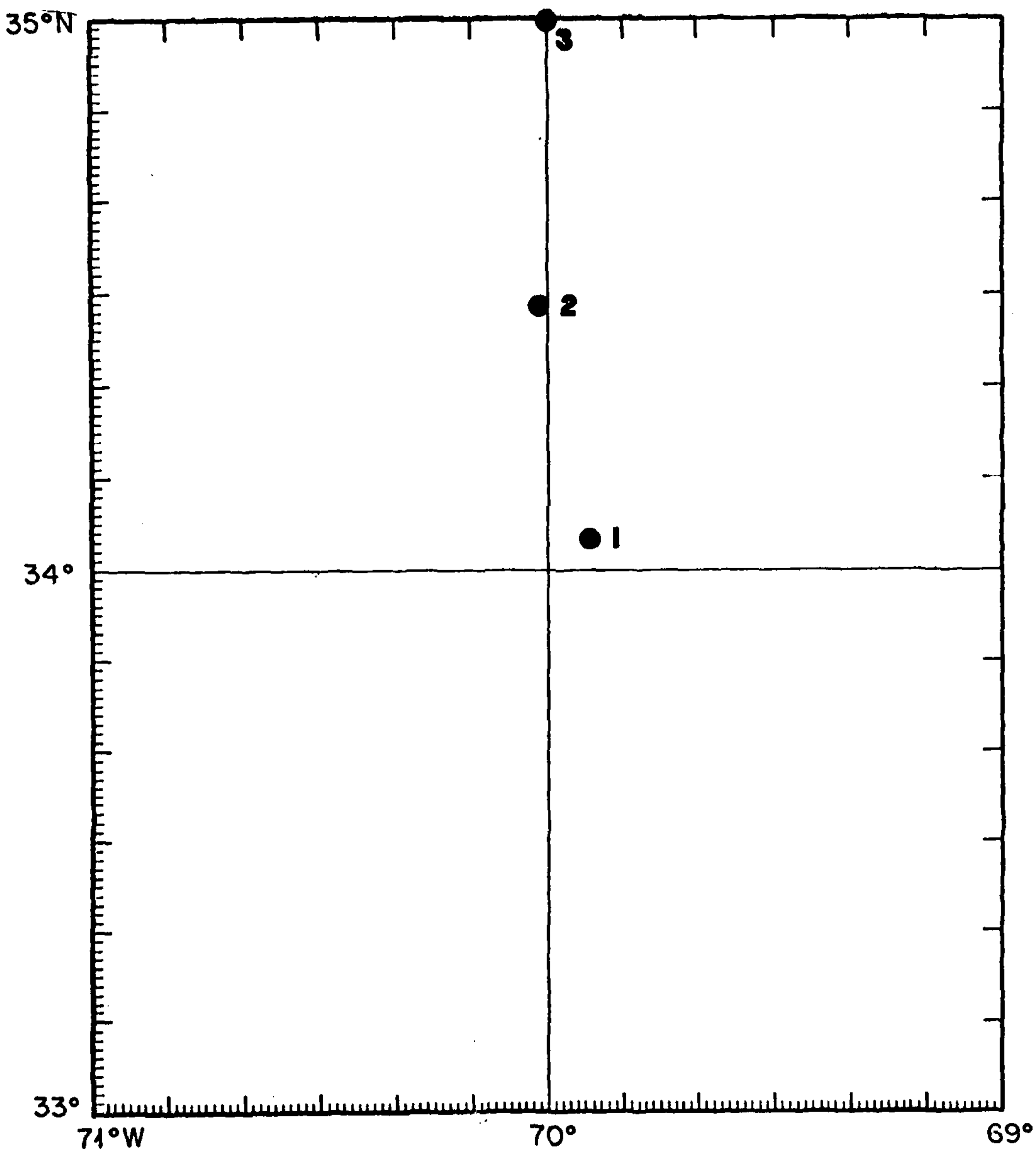


Figure 47: Chart showing the locations of CTD stations made during OCEANUS 103, Sept. 1981.

OC103 CTD 001 1981 256 0412Z 34 03.33N 69 54.32W

PRESS dbar	TEMP ^{o}C	SALIN psu	POTEMP ^{o}C	POTGRD $m^{o}C/db$	SIGMA-t kg/m**3	POTDEN kg/m**3	BR-V cph	SSPEED m/s	DYNHGT dyn m
2.	27.102	36.126	27.102	0.00	23.554	23.536	0.00	1540.5	0.0000
6.	27.115	36.176	27.115	-1.52	23.587	23.569	4.61	1540.7	.0193
10.	27.116	36.208	27.114	.16	23.611	23.594	3.94	1540.8	.0371
16.	27.120	36.230	27.117	.61	23.627	23.609	2.22	1540.9	.0620
20.	27.118	36.235	27.114	1.29	23.631	23.614	1.87	1541.0	.0777
26.	27.115	36.241	27.109	2.32	23.636	23.620	1.55	1541.1	.1048
30.	27.098	36.237	27.091	5.44	23.639	23.623	1.74	1541.1	.1209
36.	27.034	36.236	27.026	25.41	23.658	23.643	14.32	1541.1	.1471
50.	24.582	36.554	24.571	165.19	24.663	24.649	11.19	1535.9	.1997
66.	23.216	36.610	23.202	118.73	25.111	25.098	9.79	1532.8	.2484
76.	22.579	36.667	22.564	12.25	25.338	25.326	7.17	1531.5	.2764
100.	21.319	36.669	21.300	63.86	25.694	25.684	4.92	1528.6	.3360
126.	20.320	36.640	20.297	46.88	25.944	25.935	6.19	1526.3	.3940
150.	19.564	36.615	19.537	23.26	26.126	26.118	4.41	1524.6	.4430
200.	18.697	36.574	18.662	15.41	26.318	26.312	2.96	1522.9	.5351
250.	18.322	36.555	18.279	3.76	26.399	26.395	1.82	1522.6	.6219
300.	18.054	36.530	18.002	10.63	26.447	26.445	1.73	1522.7	.7071
350.	17.868	36.511	17.807	6.07	26.479	26.479	1.17	1522.9	.7913
400.	17.718	36.495	17.649	.06	26.504	26.506	1.14	1523.3	.8747
450.	17.542	36.471	17.465	.99	26.529	26.532	1.40	1523.6	.9578
500.	17.274	36.425	17.189	14.07	26.559	26.564	1.51	1523.6	1.0408
550.	16.756	36.321	16.665	20.87	26.603	26.609	2.21	1522.7	1.1223
600.	15.949	36.169	15.853	4.27	675	26.682	2.36	1520.9	1.2020
650.	15.018	36.009	14.918	20.76	26.762	26.769	2.61	1518.7	1.2783
700.	13.922	35.834	13.819	19.69	26.865	26.871	2.70	1515.8	1.3498
750.	12.964	35.689	12.859	26.78	26.952	26.956	2.96	1513.3	1.4174
800.	11.631	35.506	11.526	17.83	27.070	27.073	2.98	1509.4	1.4797
900.	9.410	35.234	9.306	21.28	27.254	27.252	2.94	1502.8	1.5899
1000.	7.567	35.118	7.464	8.23	27.451	27.446	2.53	1497.5	1.6809
1100.	6.407	35.079	6.302	2.29	27.582	27.576	2.19	1494.6	1.7548
1200.	5.679	35.072	5.570	4.02	27.671	27.664	1.32	1493.3	1.8177
1300.	5.188	35.055	5.074	2.49	27.718	27.710	1.18	1493.0	1.8742
1400.	4.826	35.037	4.706	6.67	27.746	27.738	.85	1493.2	1.9275
1500.	4.576	35.026	4.449	2.71	27.765	27.758	.84	1493.8	1.9785
1600.	4.384	35.012	4.250	2.57	27.776	27.769	.80	1494.7	2.0286
1800.	4.125	34.999	3.975	.29	27.794	27.788	.74	1496.9	2.1270
2000.	3.952	35.000	3.785	.73	27.813	27.809	.59	1499.6	2.2239
2200.	3.763	34.996	3.579	.57	27.829	27.826	.63	1502.1	2.3195
2400.	3.528	34.983	3.329	.30	27.842	27.841	.67	1504.5	2.4138
2500.	3.442	34.981	3.234	2.11	27.849	27.848	.65	1505.8	2.4602
2600.	3.366	34.977	3.149	.46	27.853	27.853	.53	1507.2	2.5064
2800.	3.218	34.967	2.984	.88	27.860	27.861	.49	1509.9	2.5986
3000.	3.075	34.957	2.823	.85	27.865	27.867	.74	1512.7	2.6904
3200.	2.915	34.947	2.645	.33	27.872	27.875	.59	1515.4	2.7814
3400.	2.750	34.937	2.462	1.85	27.879	27.883	.55	1518.1	2.8713
3600.	2.620	34.931	2.314	.06	27.886	27.890	.48	1521.0	2.9601
3800.	2.507	34.922	2.181	.48	27.889	27.895	.49	1523.9	3.0480
4000.	2.426	34.917	2.079	.86	27.891	27.899	.41	1527.0	3.1358
4200.	2.369	34.911	2.001	.32	27.892	27.901	.37	1530.2	3.2240
4400.	2.340	34.906	1.950	.06	27.890	27.900	.24	1533.6	3.3129
4600.	2.318	34.902	1.904	.17	27.889	27.901	.29	1536.9	3.4076
4800.	2.314	34.899	1.876	.12	27.887	27.901	.22	1540.4	3.4961
5000.	2.309	34.895	1.846	.17	27.884	27.900	.21	1543.8	3.5906
5200.	2.297	34.889	1.809	.03	27.880	27.898	0.00	1547.3	3.6871

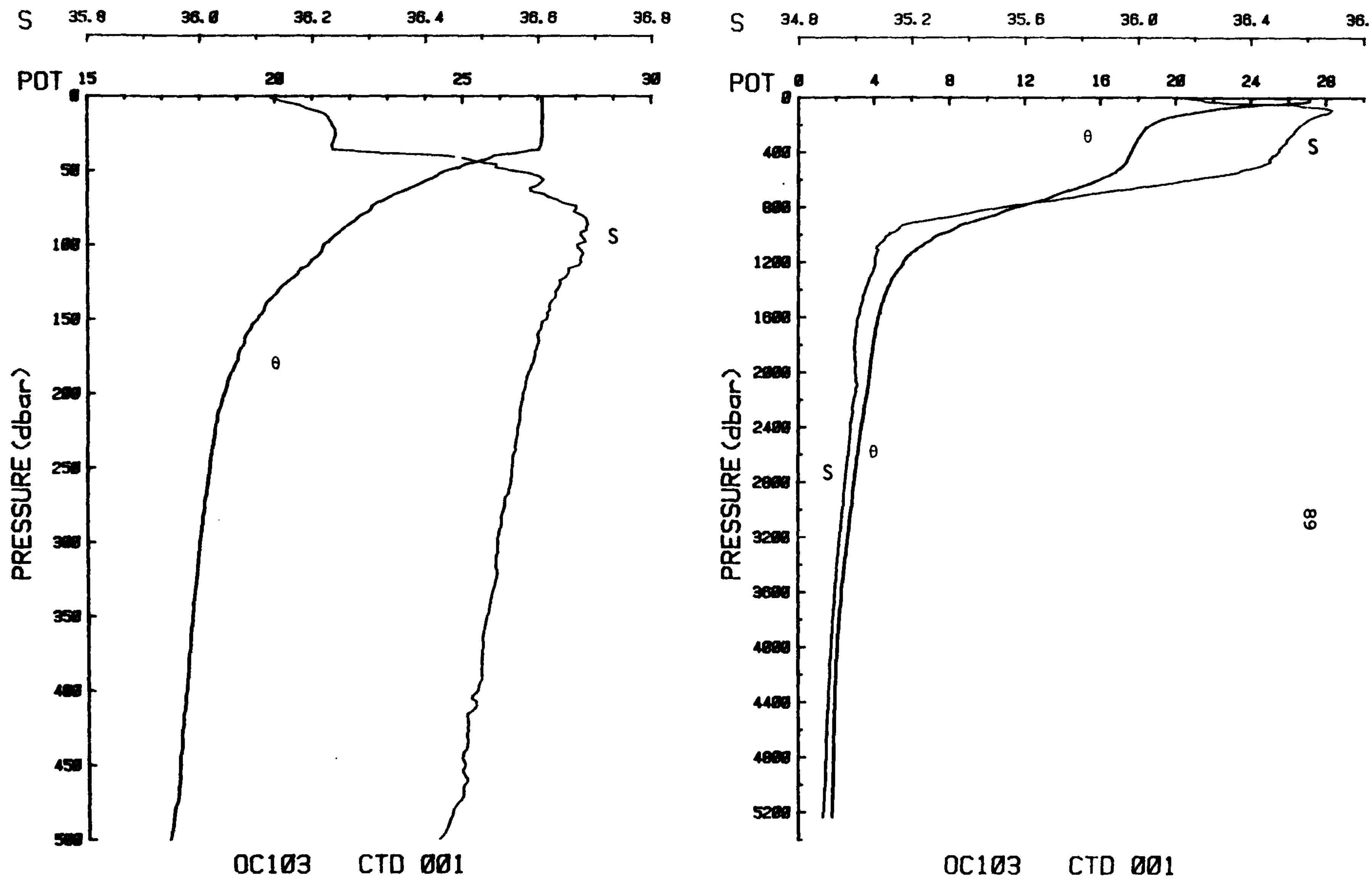


Figure 48: Profiles of potential temperature and salinity from OCEANUS 103, CTD number 1, 13 Sept. 1981.

OC103 CTD 003 1981 257 1845Z 35 00.02N 70 00.09W

PRESS dbar	TEMP °C	SALIN psu	POTEMP °C	POTGRD m°C/db	SIGMA-t kg/m**3	POTDEN kg/m**3	BR-V cph	SSPEED m/s	DYNHGT dyn m
2.	26.423	36.310	26.423	0.00	23.909	23.891	0.00	1539.2	0.0000
6.	26.255	36.303	26.254	52.01	23.957	23.939	4.96	1538.9	.0154
10.	26.224	36.306	26.222	4.81	23.969	23.951	2.93	1538.9	.0314
16.	26.176	36.311	26.173	8.40	23.987	23.971	2.92	1538.8	.0555
20.	26.158	36.314	26.153	5.72	23.995	23.979	2.14	1538.9	.0726
26.	26.139	36.312	26.134	2.39	24.000	23.984	1.80	1538.9	.0948
30.	26.129	36.314	26.123	2.99	24.004	23.988	1.93	1539.0	.1105
36.	26.101	36.312	26.093	5.79	24.012	23.996	5.68	1539.0	.1345
50.	23.260	36.523	23.250	459.93	25.032	25.018	17.42	1532.6	.1844
66.	20.992	36.571	20.980	74.58	25.710	25.697	9.76	1527.0	.2266
76.	20.293	36.581	20.279	65.80	25.906	25.895	7.23	1525.3	.2484
100.	19.560	36.610	19.542	17.04	26.123	26.112	3.90	1523.7	.2965
126.	19.048	36.583	19.026	21.63	26.236	26.226	3.32	1522.7	.3455
150.	18.722	36.574	18.695	9.18	26.313	26.304	2.99	1522.1	.3886
200.	18.275	36.541	18.241	7.78	26.400	26.394	2.06	1521.7	.4753
250.	18.057	36.521	18.014	2.03	26.440	26.436	1.44	1521.8	.5598
300.	17.939	36.520	17.887	4.00	26.468	26.466	1.36	1522.3	.6434
350.	17.763	36.498	17.703	3.05	26.495	26.495	1.16	1522.6	.7268
400.	17.655	36.484	17.586	2.29	26.511	26.513	1.18	1523.1	.8096
450.	17.407	36.439	17.331	3.84	26.537	26.540	1.48	1523.2	.8925
500.	17.001	36.360	16.918	7.36	26.574	26.579	1.96	1522.7	.9744
550.	16.280	36.224	16.191	7.29	26.641	26.646	2.21	1521.2	1.0546
600.	15.454	36.080	15.360	12.30	26.720	26.725	2.03	1519.3	1.1318
650.	14.576	35.934	14.477	7.82	26.802	26.808	2.48	1517.2	1.2058
700.	13.663	35.794	13.561	26.99	26.889	26.894	2.50	1514.9	1.2762
750.	12.535	35.629	12.432	15.16	26.991	26.994	2.60	1511.8	1.3416
800.	11.422	35.475	11.318	4.74	27.086	27.088	2.20	1508.6	1.4027
900.	9.400	35.223	9.295	28.63	27.247	27.245	2.77	1502.8	1.5127
1000.	7.570	35.108	7.467	8.95	27.442	27.438	2.17	1497.5	1.6045
1100.	5.981	35.052	5.879	2.14	27.617	27.609	2.38	1492.9	1.6765
1200.	5.278	35.041	5.172	7.56	27.696	27.687	1.41	1491.7	1.7354
1300.	4.955	35.031	4.843	-1.24	27.726	27.718	1.21	1492.0	1.7896
1400.	4.652	35.016	4.534	4.27	27.749	27.741	.76	1492.4	1.8414
1500.	4.477	35.009	4.352	.10	27.763	27.756	.75	1493.4	1.8920
1600.	4.333	35.004	4.200	1.39	27.775	27.768	.79	1494.4	1.9419
1800.	4.071	34.989	3.922	6.73	27.792	27.786	.75	1496.7	2.0407
2000.	3.912	34.989	3.745	.52	27.808	27.804	.64	1499.4	2.1376
2200.	3.751	34.987	3.568	.54	27.823	27.820	.68	1502.1	2.2338
2400.	3.617	34.984	3.416	.84	27.834	27.833	.71	1504.9	2.3295
2500.	3.482	34.977	3.273	.14	27.842	27.841	.66	1506.0	2.3770
2600.	3.373	34.970	3.156	2.46	27.847	27.847	.77	1507.2	2.4240
2800.	3.178	34.959	2.944	.64	27.857	27.858	.50	1509.8	2.5165
3000.	3.000	34.948	2.750	.38	27.865	27.867	.73	1512.4	2.6082
3200.	2.840	34.939	2.572	-.04	27.873	27.875	.77	1515.1	2.6985
3400.	2.672	34.930	2.386	-.03	27.881	27.884	.56	1517.8	2.7867
3600.	2.524	34.921	2.220	.26	27.887	27.891	.54	1520.6	2.8737
3800.	2.422	34.918	2.099	.13	27.893	27.898	0.00	1523.6	2.9599

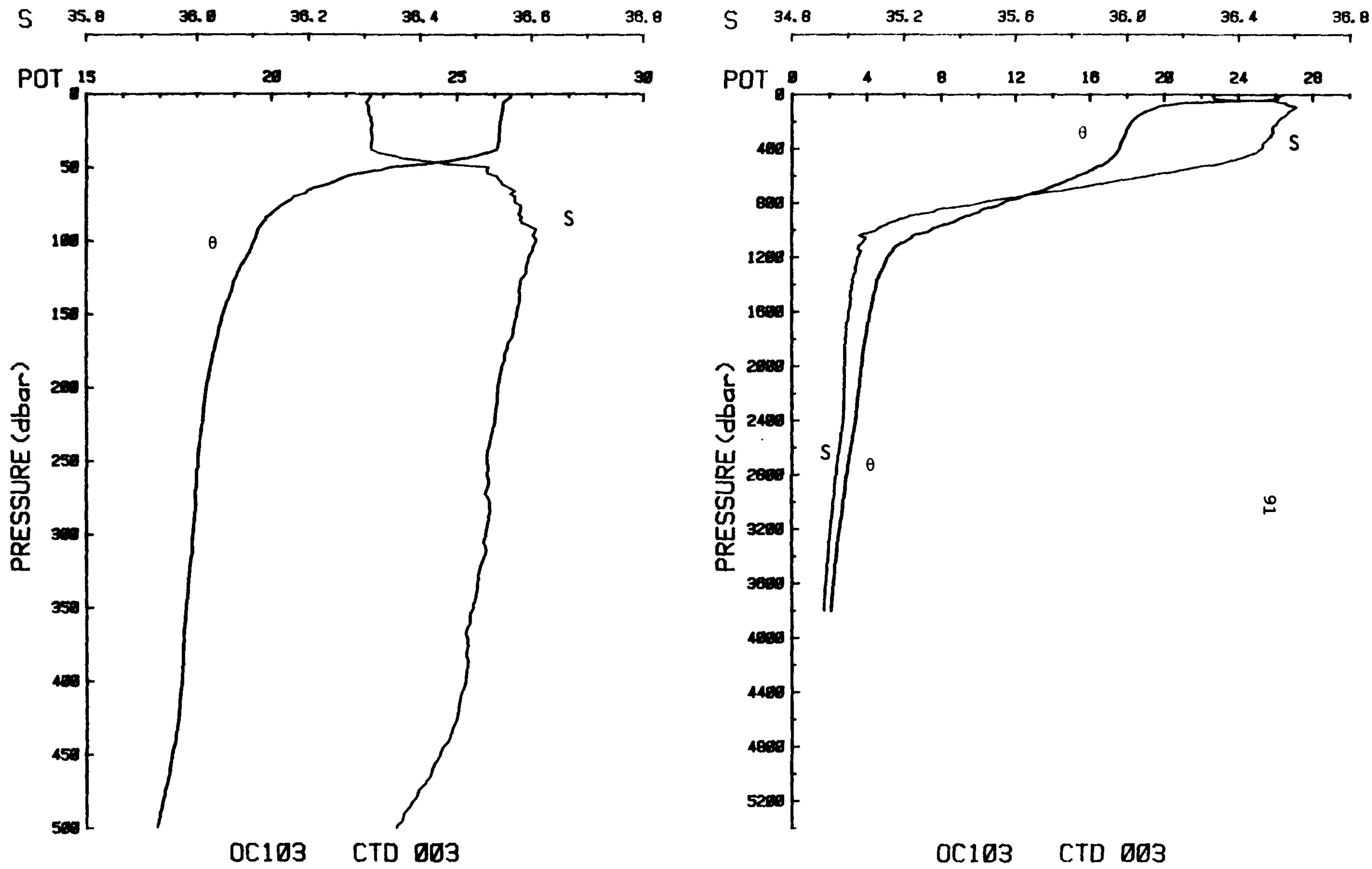


Figure 49: Profiles of potential temperature and salinity from OCEANUS 103, CTD number 3, 14 Sept. 1981.

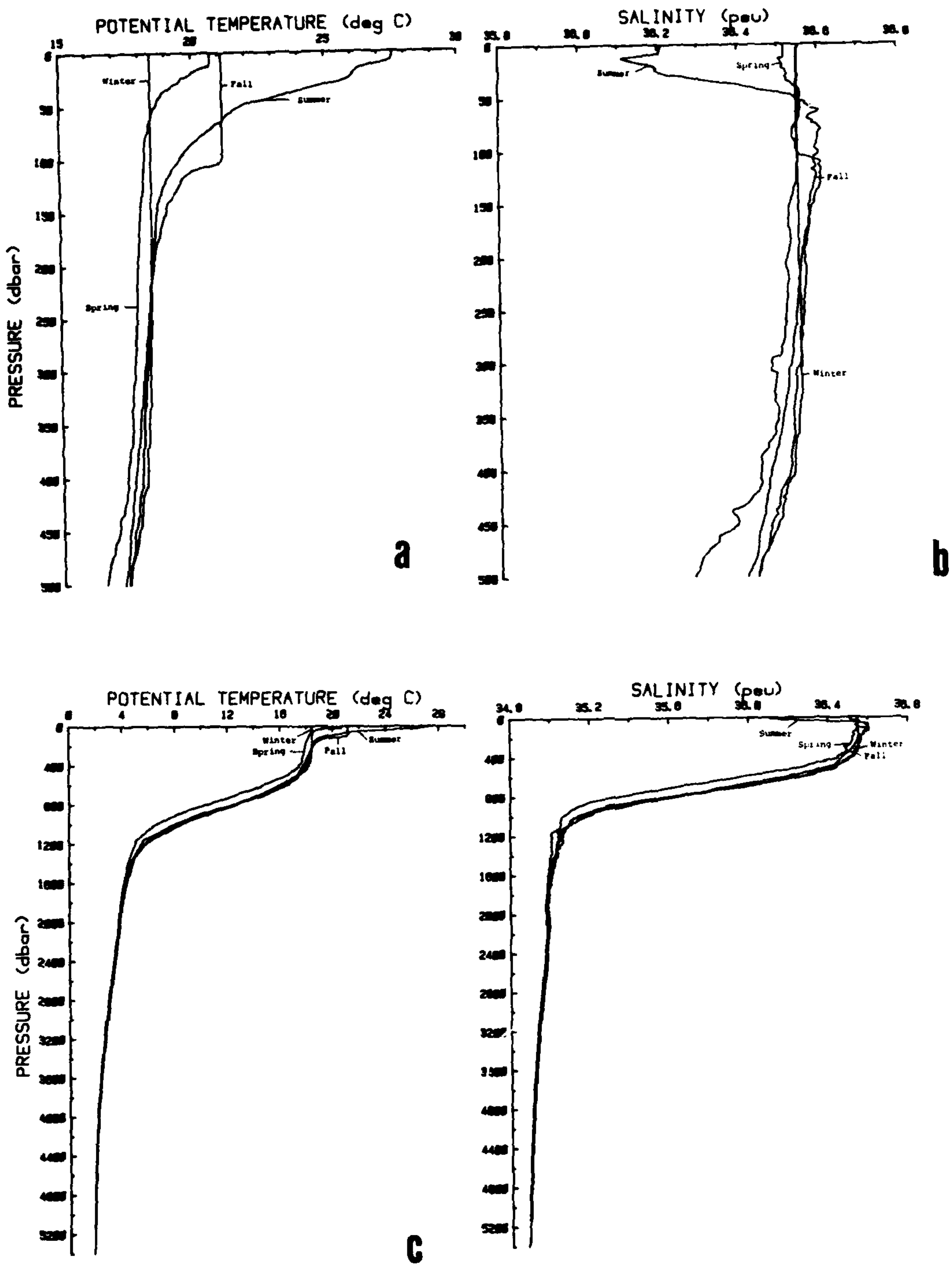


Figure 50: Seasonal profiles of potential temperature and salinity for the upper 500 meters (a and b respectively) and for the entire cast (c and d respectively). Summer = OC 85 station 2; Fall = KN 85 station 3; Winter = KN 87; Spring = OC 96 station 7.

f. Telemetered Data

After losing the LOTUS-1 surface buoy deployed in May 1980 plans for another surface buoy required a means of monitoring the buoy position, the mooring tension and sea conditions. Telemetry of that information via satellite seemed a viable solution. To accomplish this an ARGOS satellite based data collection and platform location system was chosen. This section of the report will briefly describe that system and present an example of the data telemetered from the LOTUS-2 buoy.

The ARGOS system consists of two TIROS satellites in orbit, each equipped with a data collection system (DCS), a platform (in our case the LOTUS-2 buoy) with a transmitter terminal, and several ground data processing centers. The platform transmitter terminal (PTT) provides the link between the platform and the satellites. The sensors on the platform are linked directly to the PTT which periodically transmits the data without the need for satellite interrogation. The DCS on board the satellite receives the data when the platform is within the satellite's coverage. The DCS records the time and date, measures the carrier frequency and demodulates the platform identification number and data. These data are then formatted and stored by one of the onboard magnetic tape recorders. Each time the satellite passes over one of the three telemetry stations, the data recorded on tape are read out and transmitted to the earth. On earth the received data are transmitted to the National Environmental Satellite Service (NESS) Center at Suitland, Maryland, from which it is transmitted to the Centre National d'Etudes Spatiales, Toulouse Space Center, France, where the ARGOS Data Processing Center is located. The processing performed at the Center permits the determination of platform position and the extraction of sensor data. From France the data is returned to Suitland, Maryland, where the most recent information received by NESS can be accessed by remote terminals over the commerical telephone lines. Data in the form of listings and computer compatible 9 track tapes are available from the ARGOS Data Processing Center.

The sensors onboard the LOTUS-2 buoy included a tensiometer for monitoring the tension in the mooring line, sea and air temperatures,

AD-A124 362 LONG TERM UPPER OCEAN STUDY (LOTUS) A SUMMARY OF THE HISTORICAL DATA AND..(U) WOODS HOLE OCEANOGRAPHIC INSTITUTION MA R P TRASK ET AL. DEC 82 WHOI-82-53 2/2

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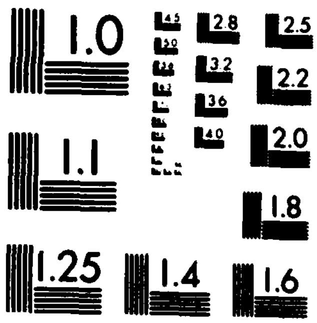

MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

barometric pressure, relative wind direction, battery and regulated voltages and water level in the buoy. On the average there were ten satellite passes per day with as many as ten transmissions per satellite pass.

Throughout the LOTUS-2 deployment the telemetered data were accessed daily by phone. Figure 51 is a plot of four telemetered variables including mooring line tension, barometric pressure, and sea and air temperature obtained during the LOTUS-2 deployment.

Mooring Motion

Figure 52 shows the daily positions of the LOTUS-2 surface mooring as calculated by the ARGOS system; some of the jitter is from the accuracy of the satellite location system (about ± 1/2 km), the rest is the buoy actually moving around. The slow drift of the buoy around its watch circle is clear; it took about two months for the buoy to circle around its anchor position. Note that the buoy does not go around its watch circle each inertial period, rather it sets over to some position determined by the mean, depth-integrated current profile and then jitters around that position according to tides and inertial oscillations.

Acoustic tracking of the LOTUS-1 surface buoy showed about 100 m rms horizontal excursions on a day-by-day basis, superimposed on a slow 1.5 km total horizontal excursion during the first two weeks; figure 8 shows the strongest currents during this time. This confirms the LOTUS-2 satellite-positioning result that daily excursions of the surface buoy are small relative to the size of the watch circle and slow excursions.

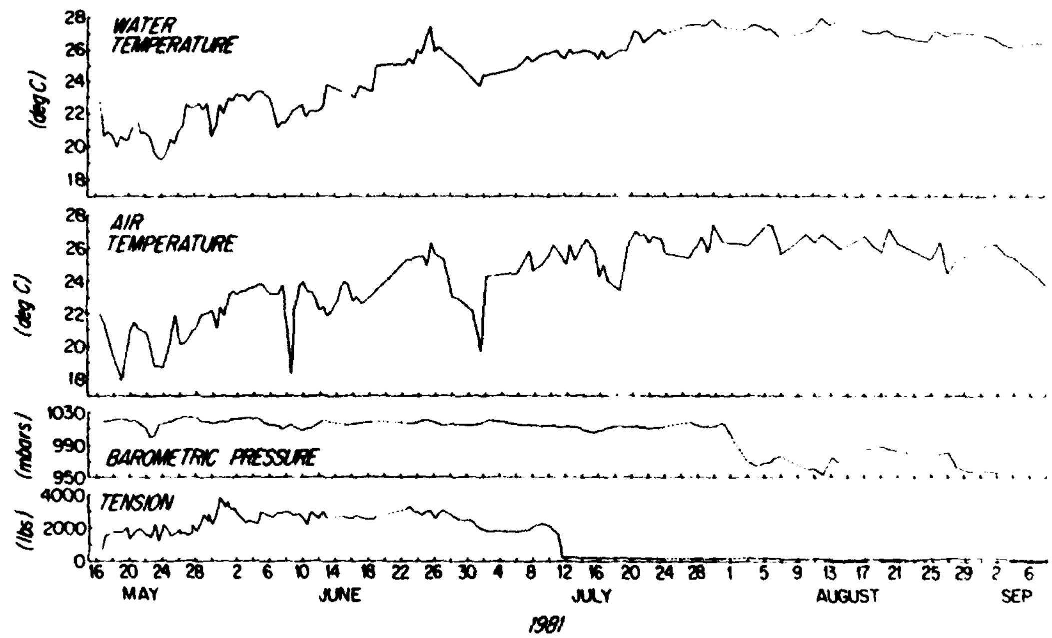

Figure 51: Telemetered data from the LOTUS-2 surface buoy.

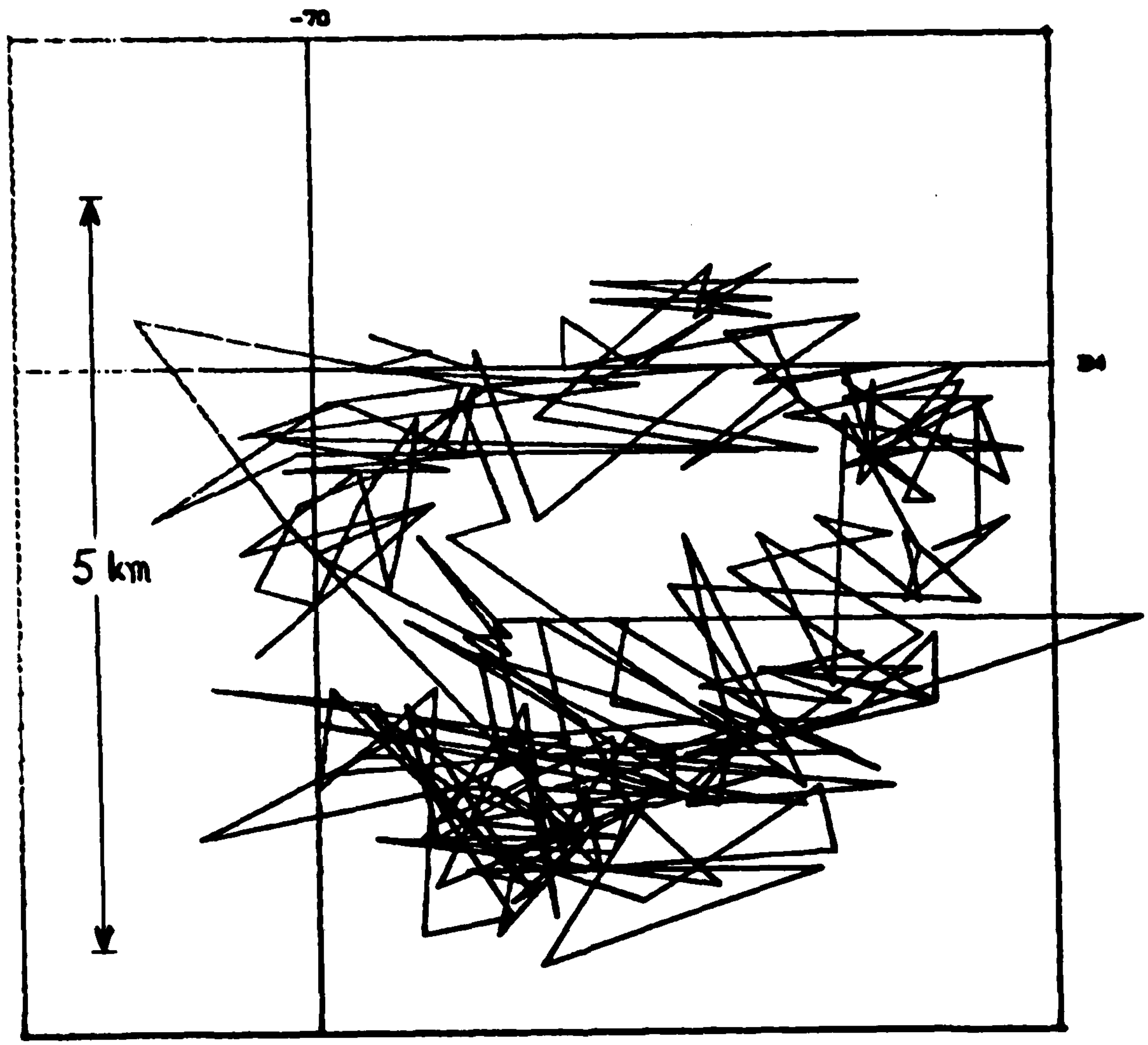

Figure 52: ARGOS system satellite tracking of the LOTUS-2 surface buoy during May-September 1981.

III. SUMMARY

The engineering test period was extremely valuable in preparing for the LOTUS science period. The opportunity to deploy moorings and instrumentation on site and then evaluate their performance with the option of making design changes prior to their science commitment will definitely improve the science data return. How representative the engineering test period was of conditions that will be encountered during the science period will only be known at the end of the experiment. This section will present a summary of the significance of the engineering period with respect to each major component of the experiment discussed in section II.

Surface Mooring Design

The almost complete recovery of the LOTUS-1 surface mooring accomplished by several dragging operations and the recovery of LOTUS-2 yielded much information that was valuable in planning future deployments. Several design changes that were incorporated as a result of observations made during the engineering test period are discussed below.

The loss of LOTUS-1 has been attributed to the failure of a Crosby-Laughlin A-342 1/2 inch master link located immediately below the VMCM at 5 meters depth. Evidence indicates that the failed master link was one of a batch of master links received in 1979 in which some were found to be cracked and broken. The master links are an alloyed steel and had been galvanized after proof testing. The failed links were returned to the manufacturer for examination. After laboratory analysis the probable cause of failure was stated as "liquid metal embrittlement". This occurred during the galvanizing process and after the stressing of the link during the proof test. The failure of the master link on LOTUS-1 occurred during a period of low to moderate tension suggesting that the mode of failure was fatigue (R. Walden, personal communication).

Evidence indicates that alloy master links can be safely used if not galvanized or if galvanized before stressing. Since neither of these alternatives appeared attractive to our mooring applications 1/2 inch galvanized steel pear rings have been substituted at all locations where master links were previously used. Pear rings were selected because they are made of steel which unlike the alloyed steel is unaffected by "liquid metal embrittlement".

Recovery of the LOTUS-1 surface mooring after it had parted required dragging since the backup buoyancy was not capable of bringing the mooring to the surface. Several factors were responsible for the insufficient buoyancy. Since the upper 13 meters of the mooring consisted largely of 1/2 inch diameter chain and only two instruments an assumption was made that if the mooring was to part it would do so below this point. Backup buoyancy was therefore calculated not considering the weight of the chain and instruments in the upper 13 meters. In addition the buoyancy did not take into consideration the potential weight increase that would occur should any instruments become flooded. Since the mooring parted at 5 meters the increased weight of the 1/2 inch chain plus one flooded instrument decreased the available buoyancy by 117 pounds.

A less obvious complication became apparent when modelling the mooring in the configuration it assumed after the mooring was released from its anchor. When the parted mooring was released from the anchor, the backup buoyancy approached the surface. The chain, wire rope and instruments that were originally near the top became the new "anchor". In this configuration the mooring resembled a poorly buoyed subsurface mooring. In the presence of a 20 cm/sec current (typical for the area at this time) the vertical component of tension approaches zero. Thus the mooring could not come to the surface (P. Clay, personal communication).

Another factor which contributed to the lack of buoyancy was discovered at the time the mooring was recovered. One glass ball was missing from the backup buoyancy cluster. The glass ball had probably broken away from the mooring during deployment.

Following the loss of the LOTUS-1 buoy a new buoy was designed. The basic improvement made to the LOTUS-1 design was a stronger and smaller hull. In the design of the LOTUS-1 buoy the 12-foot hull consisted of butt welded aluminum plate. Previous experience with this form of construction had shown that these welded joints could easily split open if the buoy should hit against the ship during deployment or recovery. For this reason the new 10-foot buoy design included rolled 3 inch aluminum channel at the intersection of the top deck plate and the side of the hull. The channel provided a large surface to weld the aluminum plates to, strengthened the outermost perimeter of the hull, and provided a place for a rubber bumper. The new buoy design was first used in LOTUS-2, and a second such buoy was built for LOTUS-3.

Inspection of the LOTUS-2 buoy after recovery revealed signs of wear at the bolts connecting the rigid bridle to the buoy hull. Bolt diameters were therefore increased to one inch at these locations.

Failure of the telemetered tensiometer on LOTUS-2 necessitated a redesign of the tensiometer so that it could withstand the constant buoy motion. The tensiometer, located at the apex of the rigid bridle, had received all the flexure between the buoy and the mooring line resulting in its failure. A universal joint was added just below the rigid bridle in order to minimize the flexing occurring at the tensiometer. The flexure occurring between the buoy and the mooring line is due largely to the tilting of the buoy as it follows the slope of wind generated waves. Since the buoy aligns itself with the wind by means of a large vane it is also aligned in the propagation direction of the wind waves. The tilting motion of the buoy is therefore in the same plane as that of the vane. The pivot pin of the universal joint was placed perpendicular to the vane such that the flexure between the rigid bridle and the mooring line would occur in the same plane as that of the pivotal direction of the universal joint. This in turn reduced the flexing that was originally occurring at the base of the tensiometer.

Breaking strength tests conducted on the nylon line recovered from LOTUS-2 indicated that the upper 1000 meters had undergone a significant decrease in breaking tension. The breaking tension of the 3/4 inch diameter nylon line is normally approximately 14500 pounds. On LOTUS-2 the nylon line at and greater than 1000 meters from the top of the nylon had breaking tensions of nearly 14300 pounds. Test samples taken from the top of the nylon broke at only 11000 pounds tension. The decrease in breaking strength is believed to have occurred because the upper part of the mooring (wire rope and instruments) is essentially rigid whereas the nylon immediately below is compliant and absorbs most of the vertical motions transmitted by the buoy. To compensate for the degradation, the diameter of the nylon line in the upper 1000 meters was increased to 13/16 inch.

Current Meters

Since the upper 100 meter current measurements made from the surface mooring are strongly dependent on the VMCM, experience with these instruments was needed. The engineering test period not only provided the opportunity to deploy two of these relatively new instruments at the LOTUS site but also provided a period of time whereby experience was gained through other experiments which were dependent on their use.

During the engineering test period there were several changes made to the VMCM both mechanically and electronically. One area of particular concern has been the propellor assemblies and their survivability during a deployment period. One design change that has occurred has been with the propellor shaft and the method for holding the propellors on the shaft. Earlier shafts had a tapped hole in the end which would accept a screw that retained the propellor. The screws were found to back out allowing the propellors to fall off the shaft. The newer design shaft has a threaded end on which two nuts can be placed and tightened against each other.

Other changes have occurred in the sensor hub assembly. In several instruments the screws which held the end caps on the hubs backed out which resulted in the loss of the internal hub components and the subsequent flooding of the entire sensor assembly. Upon discovery of this defect the hub assembly procedures were modified to include the use of an adhesive on the threads of the screws to prevent them from backing out. The use of more suitable hardware is planned for future deployments.

Several different types of bearings have been used in the VMCM sensor assembly. Excessive wear has been a problem in past deployments. Different combinations of materials and bearing designs continue to be tested in search of a bearing that can survive without hindering the performance of the instrument.

The first commercially available VMCM's had propellor blades made of Noryl, a phenylene oxide, chosen for its extremely low water absorption characteristic. The Noryl blades however were susceptible to breaking at the base of the blades. Previous experience with several Delrin pieces (an acetal homopolymer) used on the VACM's suggested that it could possibly be a good material for the VMCM propellors. The use of Delrin blades in several deployments appears to have reduced the incidence of broken blades, however the problem has not been totally eliminated.

Aanderaa Thermistor Chains

Aanderaa thermistor chains were deployed on three occasions during the engineering test period. Problems encountered during their deployments included tape transport failures, encoder bearing problems, and seawater leakage into the thermistor cables. Each malfunction was evaluated and with the exception of the cable problems a scheme for either preventing the problem in the future or for detecting it before deployment was devised. Instrument checkout procedures were modified in order to address these malfunctions. Prior to each instrument's predeployment checkout it is set at a fast sampling rate and run for approximately one week in a cold (4°C) environment. Problems resulting from the cold temperatures or wear (major causes of previous failures) can become apparent in this time frame and be corrected. The thermistor cables were returned to the manufacturer and repaired by an improved method which made use of a more flexible potting material. The deployments during the engineering period also provided an opportunity to try several different methods of attaching the thermistor cables to the mooring wire and to select that method which best secured the cables. The clamps manufactured by the Stauff Corporation, which firmly grasp both the mooring wire and the thermistor cable, have been used on several occasions with satisfactory results.

CTD

The LOTUS CTD was acquired early in the engineering test period, which provided adequate time to become familiar with it and its operation at sea. During the engineering test period the CTD was used on five cruises. Based on the experience gained during these cruises additions and modifications were made to the system in order to facilitate the handling and data processing. Additions to the CTD included a pinger for depth determination, a messenger activated water sampling system for conductivity calibration, and two underwater switches for turning the CTD off at the bottom to conserve battery power and for switching the pinger to a double ping rate when the sample bottles are tripped. Modifications included the placement of a file gap on the cassette tape each time the CTD is turned on and the rearrangement of several components in the internal recording module of the CTD to facilitate tape removal and overall handling at sea.

Aside from evaluating the instrumentation the engineering period provided a time for collecting background data from the LOTUS site in order to become familiar with the types of features and conditions that might be expected there such as strong inertial motions and occasional Gulf Stream rings.

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APPENDIX I: Mooring Drawings

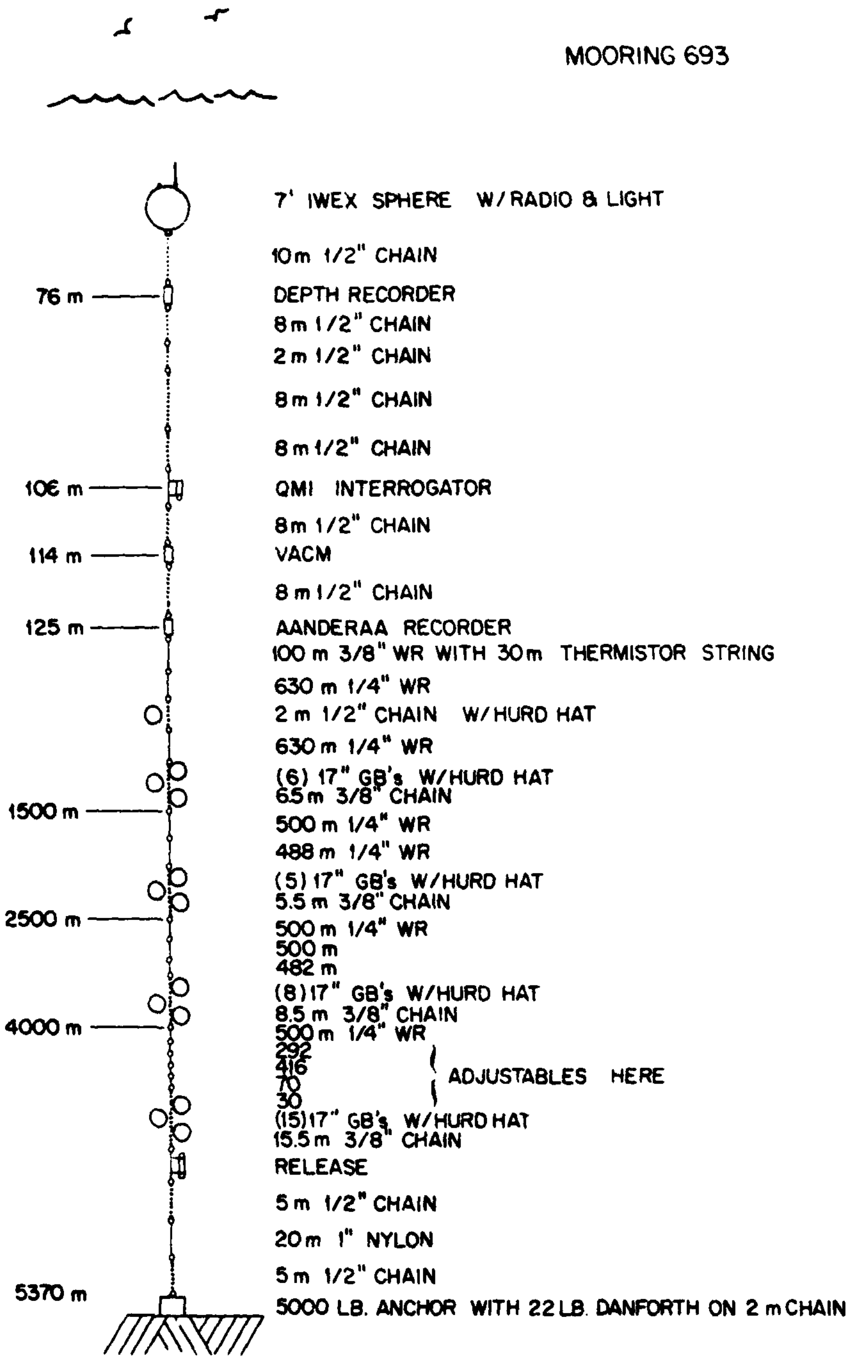

Figure A-1: Mooring diagram of mooring number 693 set in May 1980.

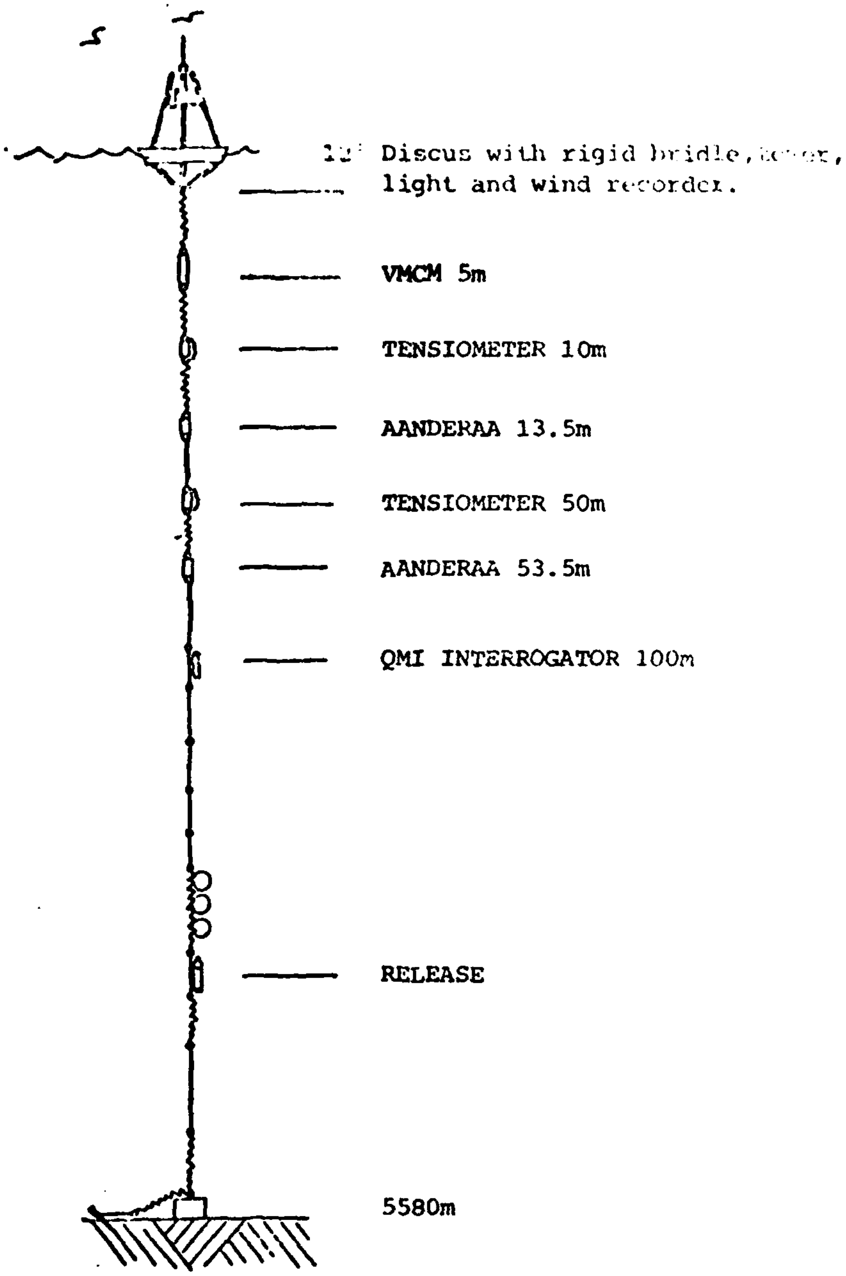

Figure A-2: Mooring diagram of mooring number 694 set in May 1980.

MOORING 733

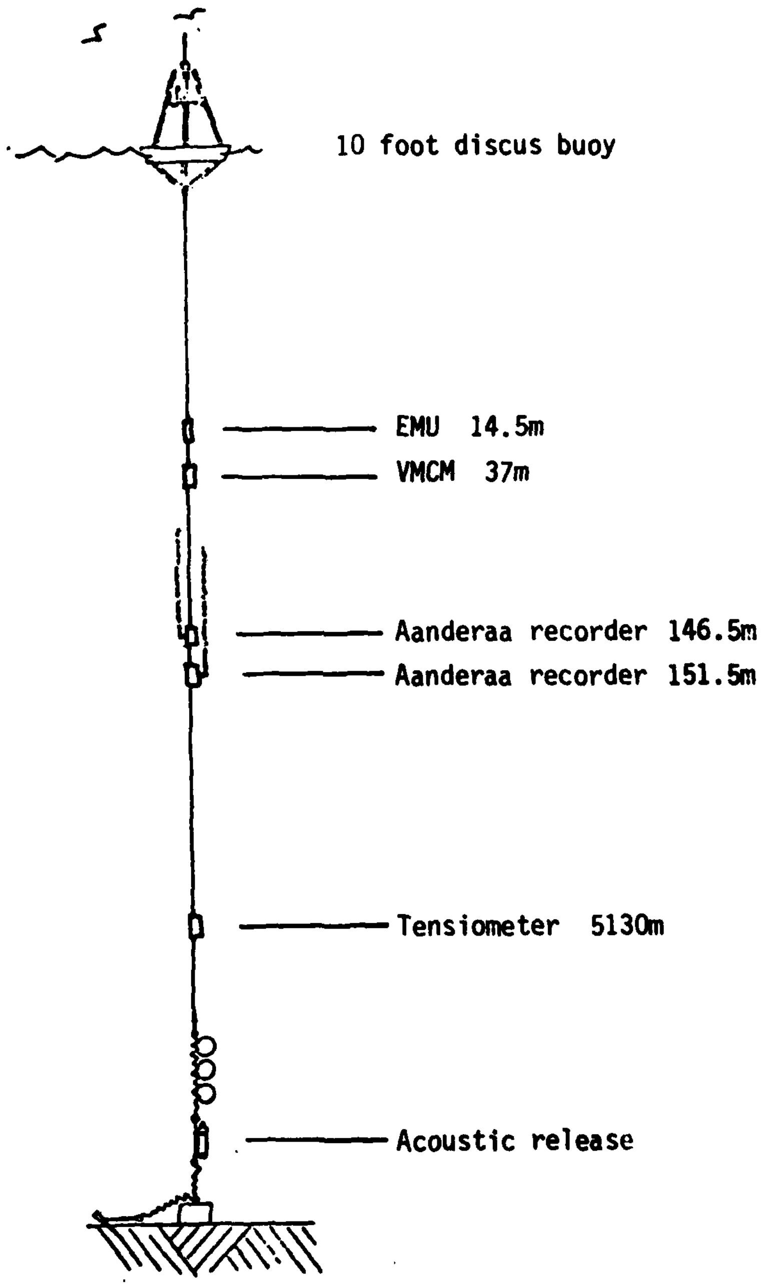

Figure A-3: Mooring diagram of mooring number 733 set in May 1981.

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